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نموذج رقم (١٨)
اقرار والتزام بالمعايير الأخلاقية والأمانة العلمية
وقوانين الجامعة الأردنية وأنظمتها وتعليماتها
لطلبة الماجستير

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تخصص: الإدارة المتكاملة للموارد المائية الكليـــــة: العلوم

عنوان الرسالة: Non-Revenue water in Small water Distribution system

اعلن بأنني قد التزمت بقوانين الجامعة الأردنية وأنظمتها وتعليماتها وقراراتها السارية المفعول المتعلقة باعداد رسائل الماجستير عندما قمت شخصيا" باعداد رسالتي وذلك بما ينسجم مع الأمانة العلمية وكافة المعايير الأخلاقية المتعارف عليها في كتابة الرسائل العلمية. كما أنني أعلن بأن رسالتي هذه غير منقولة أو مستلة من رسائل أو كتب أو أبحاث أو أي منشورات علمية تم نشرها أو تخزينها في أي وسيلة اعلامية، وتأسيسا" على ما تقدم فانني أتحمل المسؤولية بأنواعها كافة فيما لو تبين غير ذلك بما فيه حق مجلس العمداء في الجامعة الأردنية بالغاء قرار منحي الدرجة العلمية التي حصلت عليها وسحب شهادة التخرج مني بعد صدورها دون أن يكون لي أي حق في التظلم أو الاعتراض أو الطعن بأي صورة كانت في القرار الصادر عن مجلس العمداء بهذا الصدد.

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NON-REVENUE WATER MANAGEMENT IN SANA'A WATER DISTRIBUTION SYSTEM

By

Taha M. AL-Washali

Supervisor

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Co-Supervisor

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This Thesis was Submitted in Partial Fulfillment of the Requirements for the Master's Degree of Science in Integrated Water Resources Management

Faculty of Graduate Studies
The University of Jordan

Institute for Technology and Resources Management in the Tropics and Subtropics (ITT)
University of Cologne for Applied Sciences

January, 2011

COMMITTEE DECISION

This Thesis/Dissertation (Non-Revenue Water Management in Sana'a Water Distribution System) was Successfully Defended and Approved on 18/1/2010

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DEDICATION

To The Prophet (PBUH)

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All praise and glory to Almighty Allah (SWT) who gave me strength and perseverance to keep going with this thesis even during the darkest moments.

This work in its timeframe would never be achieved without the help of many people. First lines go to my advisors; Dr. Abbas Al-omari and Dr. Lars Ribbe; without their patience, advice, and assistance, this thesis would never be submitted. I wish to place on record my gratitude to them. Special thanks go to Dr. Michael Sturm for his valuable discussions.

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Thank you Waleed Amer, without you and your help in SPSS this thesis would never be completed. I deeply appreciate the help of Ibn Alwan Group, Eng. Mohamed Abdurahman, Eng. Mohamed AL-Sewari, and Mr. Rasheed AL-Saadi.

I remain grateful to all members of my family especially those who tried to put this on LaTex.; thank you for your undimensioned encouragement. Sincere thanks go also to interviewees and respondents whose contributions are an important part of this research.

A last word goes to DAAD and IWRM program. THANK YOU for giving me the chance to be a part of this program.

PREFACE

Joerg Koelbl has put this cartoon in the preface of his PhD dissertation. I decided to do the same as it indeed conveys the message. Nevertheless, I also would like to highlight another important point; The gap between "supply side" of scientific research in the discipline of non revenue water and "demand side". If you google the term NRW you would find huge amount of proceedings and materials; simultaneously, if you search the same or similar terms in on-line libraries such as scopus , direct science, or springerlink, you would find very rare published materials. The hope is now big with some cute review papers trying to link the published knowledge to the conclusions in the field. However, more attention should be paid in order for this gap to be filled. The first step might be to bear some unfamiliar new terms and concepts proposed by practitioners of this field such as the term "non revenue water". This study presents an example for these terms and concepts. It tried hard to collect briefly the buzzwords that should be known in order to re-make up the communication between scientific research and non-revenue water. It presents the key sources in the literature till December, 2010. Then the study has Sana'a water distribution system as a case study for NRW management. I apologize for any limitation of this research, though.



Cartoon from: Water & Sanitation Program of World Bank

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LIST OF ABBREVIATIONS OR SYMBOLS

AWWA:	American Water Work Association
AZP:	Average Zone Point
BABE:	Burst And Background Estimates
BCM:	Billion Cubic Meters
DCMMS:	Data Center Maintenance and Management Software
DEM:	Digital Elevation Model
DMA:	District Metered Area
EPA:	United States Environmental Protection Agency
FAVAD:	Fixed and Variable Area Discharges
GTZ:	German Agency for Technical Cooperation
HDI:	Human Development Index
HZM:	Hour Zone Measurement
ILI:	Infrastructure Leakage Index
IWA:	International Water Association
JICA:	Japan International Cooperation Agency
Masl:	Meter above sea level
MCM:	Million Cubic Meter
MENA:	Middle East and North Africa
MNF:	Minimum Night Flow
MWE:	Ministry of Water and Environment
NRW:	Non-Revenue Water
NWRA:	National Water Resources Authority
NWSA:	National Water Supply Authority
PIIS;	Performance Indicators Information System
PIs:	Performance Indicators
SWSLC:	Sana'a Water Supply and Sanitation Local Corporation
UFW:	Unaccounted For Water
UNDP:	United Nations Development Program
W.S.P.:	when the system is pressurized
WHO:	World Health Organization
WWTP:	Waste Water Treatment Plant
Y.R.:	Yemeni Rial
24/7:	Continuous Supply

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NON-REVENUE MANAGEMENT IN SANA'A WATER DISTRIBUTION SYSTEM

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ABSTRACT

Without proper Non-Revenue Water (NRW) management, Sana'a water utility is not able to sustain its services or cover all population in Sana'a city with water service. This study aims at assessing the quantity, supply management options, and measure awareness of NRW in Sana'a water utility.

For measuring the awareness level, interviews, report analysis and awareness questionnaire with opinion questions in form of statements with five point Likert scale were conducted. Assessing NRW components involved a review of the existing methods and their applicability for the case of Sana'a water distribution system, and then, a suggested novel methodology, the reveres approach, has been developed, introduced, and implemented. For suggesting sound management options in Sana'a water distribution system, besides the interviews, literature review, social questionnaire, illegal users' questionnaire, and problem analysis have been carried out.

The study found that volume of NRW in Sana'a water distribution system made up 38.75% of system input volume of which 26.57% is apparent losses; 11.67% is real losses; and 0.51% is unbilled authorized consumption. Further analysis showed that unauthorized consumption stands for 50% of NRW volume and its main causes are poor customer- utility relation and lack of monitoring measures. Although results showed that leaks make up more than 5% of Sana'a basin safe yield, no much is expected to be reduced till the utility apply zoning principle for its network. This in turn is beyond the capacity of the utility. In consequence, the study recommended optimizing the speed and quality of repairs for reported leaks and involving the private sector to supply the right technology for achieving zoning in the network. For apparent loss reduction, the study recommended working on enhancing the customer-utility relation, customer confidence on the utility, monitoring measures, and the utility employees' commitment. For improved NRW management, the study suggested assessing NRW and drawing water balance annually, and getting use of the free NRW softwares with their associated performance indicators to allow better NRW monitoring.

Keywords

Non revenue water – management - apparent losses – real losses - Sana'a

Chapter 1

Introduction

1. 1 Area of Study

1.1.1 Water Demand Management

Water demand is rapidly increasing due to population growth, urbanization, economic development, and climate change (Cosgrove and Rijsberman, 2000). The potential responses to this increasing demand are either meeting the new demand with new resources (supply-side) or managing the consumptive demand to avoid the need of developing new resources (demand-side) (Butler and Memon, 2006).

The traditional approaches of resource development are considered as unsustainable. In contrast, the demand management, through Water Demand Management (WDM), is considered sustainable. It provides a proper solution to the water scarcity problem through shifting the responses from the traditional resource development to that of demand-oriented management (Marunga, et al., 2006).

Water Demand Management views water use as a demand that can be adjusted through various policy and technical means (Tsinde Development Consultants, 2001). The main purpose of water demand management is to meet any of the following objectives: economic efficiency, social development, social equity, environmental protection,

sustainability of water supply and services, and political acceptability (Department of Water Affairs and Forestry, 2004).

Water demand management is defined as a management approach that aims to conserve water by controlling demand through the application of measures such as regulatory, technological, economical and social at all spatial and institutional levels" (IUCN, 2002 as in Marunga, et al., 2006). Another proposed operational definition for water demand management contains five main components (1) reducing the quantity or quality of water required to accomplish a specific task, (2) adjusting the nature of the task so it can be accomplished with less water or lower quality water, (3) reducing losses in movement from source through use to disposal, (4) shifting time of use to off-peak periods, and (5) increasing the ability of the system to operate during drought seasons (Brooks, 2006).

Consequently, water loss reduction is a component of water demand management which one of its aims is reducing the losses and improving the distribution efficiency of water distribution systems (Marunga, et al., 2006).

1.1.2 Non-Revenue Water

Non-Revenue Water (NRW) is a term used to express the quantity of lost water within the distribution systems besides the amount of water that is authorized to use but not billed (such as the amount of water used for firefighting). The term Non-Revenue Water should substitute the term 'Unaccounted For Water (UFW)' as suggested by International Water Association (IWA) (Farley and Trow, 2007), and as recommended by American Water Work Association (AWWA) and Environmental Protection Agency (EPA) (EPA, 2009).

The use of the term 'Unaccounted For Water' should be discontinued, according to IWA, because of widely varying interpretations of the term worldwide on one hand and

for that all components of the water balance should be accounted for on the other hand (Alegre, et al., 2000 as cited in Lambert, 2003), and Farley and Trow, (2007). Instead, IWA has recommended a new international standard water balance for water losses using the term Non-Revenue Water (Figure 1.1). It clearly defines all the terms involved with the suggested water balance including the term Non-Revenue Water.

(a)

System Input Volume (corrected for known errors)	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption (including water exported)	Revenue Water
			Billed Unmetered Consumption	
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non-Revenue Water (NRW)
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Unauthorised Consumption	
			Customer Metering Inaccuracies	
		Real Losses	Leakage on Transmission and/or Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to point of Customer metering	

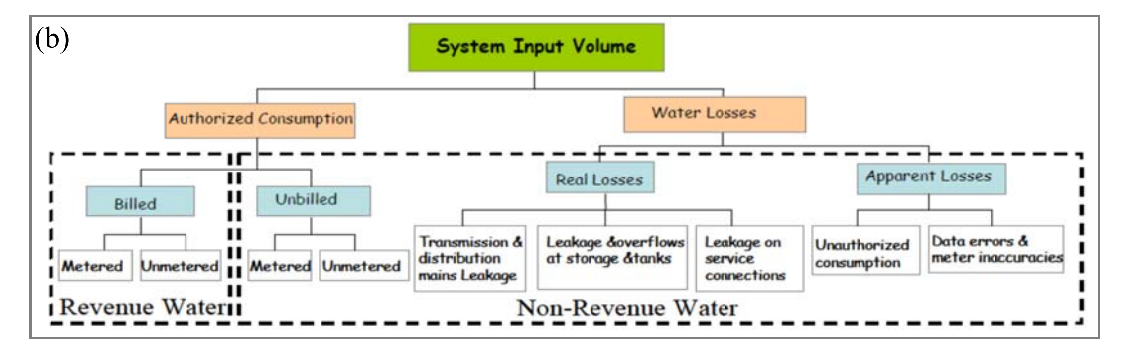


Figure 1.1.a & b: Components of IWA Standard Water Balance. Source: a: Farley and Trow (2007), b: Halfawy and Hunaidi (2008)

Unlike Unaccounted For Water which is water losses in Figure 1.1, Non-Revenue Water (NRW) is the difference between the amount of water put into the distribution system and that billed to consumers (Farley and Trow, 2007). It comprises three components; real (physical) losses, apparent (commercial) losses, and unbilled authorized consumption (Kingdom et al, 2006). The first two components are of

substantial proportion in NRW while unbilled authorized consumption is usually a small proportion especially in utilities of high NRW. Figure 1.1 illustrates the three components of NRW apparent losses, real losses, and unbilled authorized consumption.

1.1.2.1 Global Level of NRW

The global level of NRW is very high. The average percentage of the global NRW is estimated at 35% (Ranhill and USAID, 2008). Further, the global volume of NRW is 48.6 Billion Cubic Meter (BCM) per Year of which 32.7 BCM is real (physical) losses (Kingdom, et al., 2006). Additionally to water wastage of this amount, this costs water utilities worldwide US$14 billion a year. Accordingly, saving half of this amount could provide water service to an additional 100 million people without further investments (Ranhill and USAID, 2008 and Kingdom, et al., 2006).

1.1.2.2 NRW in MENA Region

Non-Revenue Water level in the Middle East and North Africa (MENA) is close to the global one ranging from 15% to 60% with an average of 38%. Figure 1.2 shows the NRW level of select countries and some major cities in the MENA region (The World Bank, 2009).

1.2 General Background about Yemen

This study is carried out on the public water distribution system in Sana'a city; the capital of Republic of Yemen. Yemen is located at the southern tip of Arabian Peninsula (Figure 1.4). The country area size is 528,000 km2; It is classified as the 49th largest countries in the World (NWRA, 2006). The climate of Yemen has a predominantly semi-arid to arid climate with an average precipitation of 130 mm per year (Library of Congress, 2008 and Al-Kirshi and Abbas, 1998).

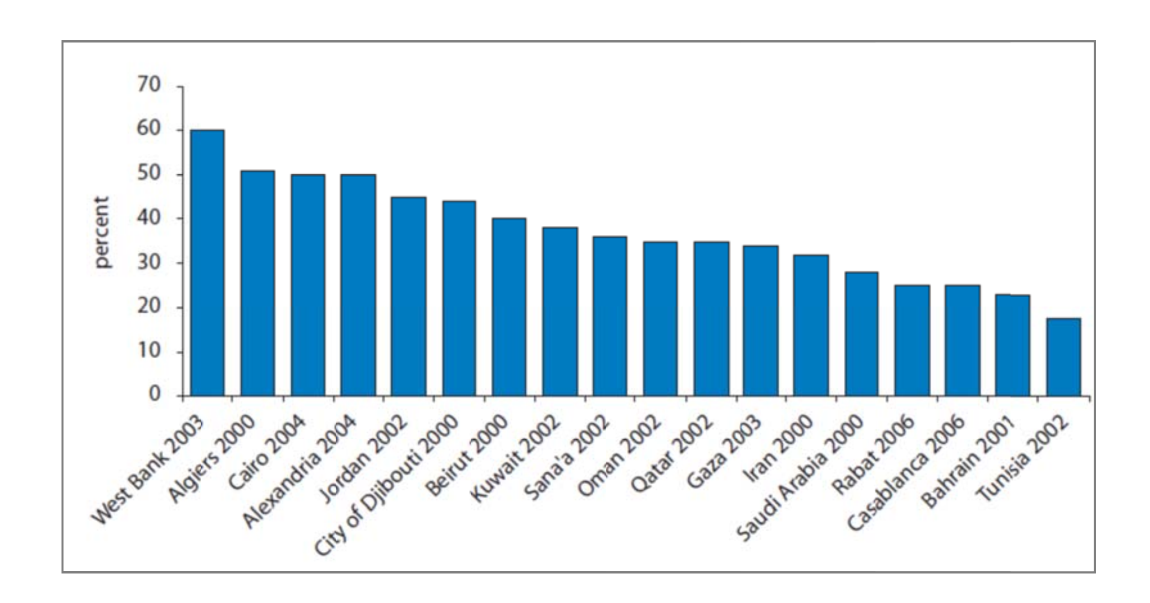


Figure 1.2: Non Revenue Water Ratio for utilities in select countries and major cities in MENA region. Source: The World Bank, 2007

Yemen's population is estimated of 22.2 million persons as of July 2007. The average annual growth rate is estimated as 3.02%. Thus, the country's population is estimated to reach 43.2 million in the year 2025 and then globally rank 32th among the largest population (Library of Congress, 2008 and NWRA, 2006).

On the other hand, Yemen is one of the poorest and least developed countries in the Arab world. It has the lowest Human Development Index[1] (HDI) ranking among the Arab states. According to United Nations Development Program (UNDP) (2009), Yemen ranks 153 out of 177 countries on the HDI.

The country is water-scarce and ranked among serious water stress countries in the Arab region (Figure 1.3). It is classified in the United Nation Human Development Reports (2009) as a country facing a water crisis. The average per capita renewable water is

[1]HDI: is a measure of life expectancy, education, and standard of living (UNDP, 2009)

estimated as of 150 cubic meter per year (JICA, 2007). Barrett, et al. (2010) stated that Yemen may be poised to become the world's first country in recent history to collapse and fail due to lack of drinkable water.

Critical water stress (More than 10,000 persons per million cubic metres)	Serious water stress (Between 5,000 and 10,000 persons per million cubic metres)	Significant water stress (Between 2,500 and 5,000 persons per million cubic metres)	Slight water stress (Less than 2,500 persons per million cubic metres)
Kuwait	Bahrain	Jordan	Egypt
UAE	Iraq	Saudi Arabia	Lebanon
	Occupied Palestinian Territory		Oman
	Qatar		Syria
	Yemen		

Figure 1.3: Levels of water stress in thirteen Arab countries, 2006. Source: UN-ESCWA as cited in (UNDP, 2009)

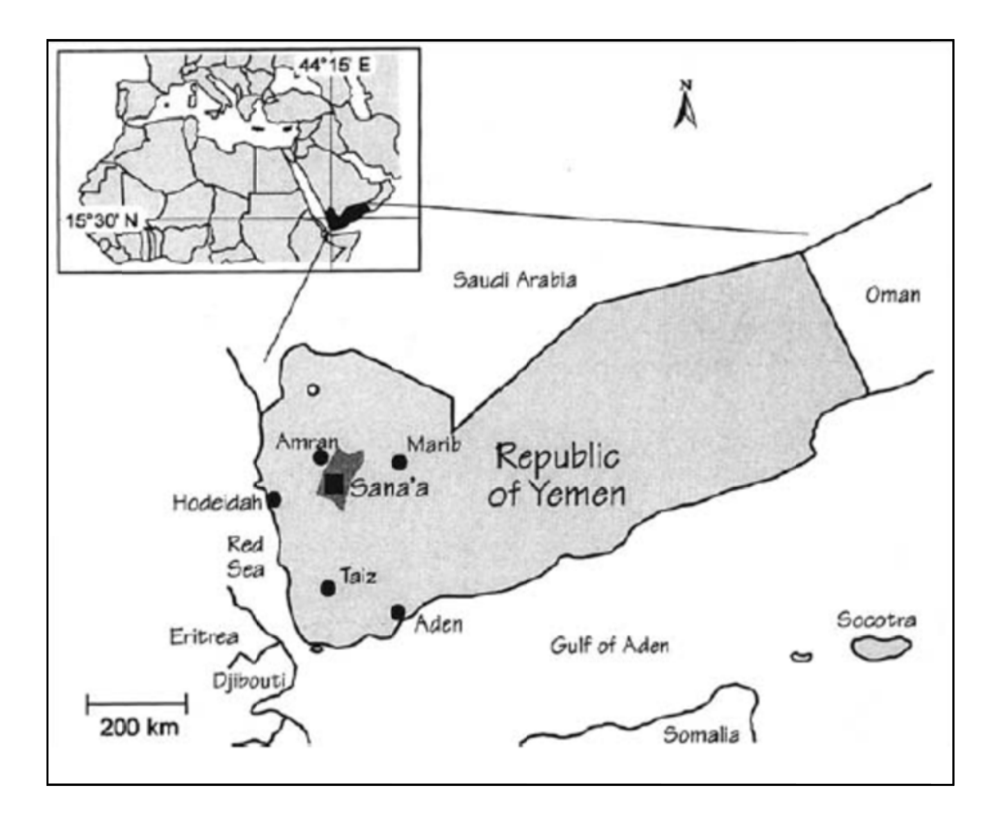
1.3 Overview of Sana'a Basin

The Sana'a basin is located in the central highlands of Yemen with an elevation ranging between 2200 and 3000 meter above sea level (masl). It covers an area of 3200km2 (Figure 1.4). The basin's climate is classified as semi-arid with an annual precipitation of 230.5 mm (JICA, 2007). Land use within the basin is of four main categories; agricultural land (33%), urban and built up land (4%), range land (27%), and unusable land (rocks outcrops) (36%) (AL-Hamdi, 2000).

Sana'a city, the capital, is located in the Sana'a basin at an elevation of about 2,200 masl (AL-Hamdi, 2000). The population of the capital is estimated to be 1.7 million inhabitants as in the 2004 Census (Central Statistical Organization, 2006).

Sana'a basin is facing a very serious water crisis. According to The Stimson Center (2010), Sana'a might be the first capital in the world to run out of water. The remaining

aquifer life of Sana'a basin is thought to be around a decade (The World Bank, 2009 and Hellegers, et al, 2008).



1997)

While the city population grows rapidly by over 7 percent annually, the water table drops by 6 to 8 meters per year because groundwater is being extracted at four times the replenishment rate (Zeug and Eckert, 2010 and NWRA, 2006). Whereas the renewable water is estimated at 50.7 Million Cubic Meter (MCM) per year, the total abstraction of the sole source of the basin's, ground water, is 269 MCM per year (JICA, 2007). This balance shows a deficit of about 218 MCM each year from the level of the safe yield of the basin. Accordingly, the central challenge facing Sana'a basin nowadays and in the foreseeable future is how to meet water demands in domestic, industrial, agricultural sectors; mainly by implementing water demand management tools such as minimizing water losses to the possible extent (The Stimson Center, 2010 and NWRA, 2006).

1.4 Overview of Sana'a Domestic Water Supply

Before the early 1970s, the major source of domestic water supply for Sana'a city was from hand dug wells located within the old town. The first water supply system was a small system installed in 1964 with only six hand-dug wells. In 1974, the National Water Supply Authority (NWSA) took over the responsibility of water supply throughout the country (GTZ, 2009 and Harza, 2006).

NWSA has its own identity with financial and administrative independence. Consequently, the whole water supply systems in the country were over-centralized through NWSA which, in turn, was under the capacity of the Ministry of Electricity and Water (GTZ, 2009).

In 2000, a decentralization process has been started, and the Sana'a Water Supply and Sanitation Local Corporation (SWSLC) was created (GTZ, 2009).Back then, Sana'a Water Utility, SWSLC, took over the responsibility of water supply in Sana'a city (Ministry of Legal Affairs, 2000).

Currently, Sana'a water utility, SWSLC, covers about 55% of the city population with the water service. The rest of the city is covered by the private sector through some separate private agencies; namely, the water tankers, and small private wells with small distribution networks (The World Bank, 2009).

On the other hand, Sana'a water network is very old. Since its start in the 1960s, the network expanded randomly and five administrative zones in the system were defined geographically with interlocked networks accompanied with shared water feeding sources (Figure 1.5). Due to dwindling of water resources in the city, age of the network, and intermittent supply, operational fatigue in the network accelerate the depreciation of the network and cause increasing of leakages in the network.

Sana'a water utility, SWSLC, faces a lot of challenges, and difficulties in covering and providing the water service. The main challenge counters Sana'a water utility is to handle the rapid population growth and the city expansion (Harza, 2006) since Sana'a city expands rapidly with an annual population growth rate of 7.12% (Zeug and Eckert, 2010). In contrast, a report of Harza (2006) highlights that main deficiency of Sana'a water system includes but not limited to the following points:

- Shortage in supply that necessitates a rationing program
- Unplanned network expansion
- Impacts of intermittent supply that consists of network deterioration, prolonged periods of negative pressures accompanied by water quality deterioration, and inadequate pressure in some parts of the network.

Accordingly, Sana'a water distribution system has deficiency in water quality, water quantity, and pressures in the network, and therefore, a deficiency in the general level of service for the current 55% served people of the city's population.

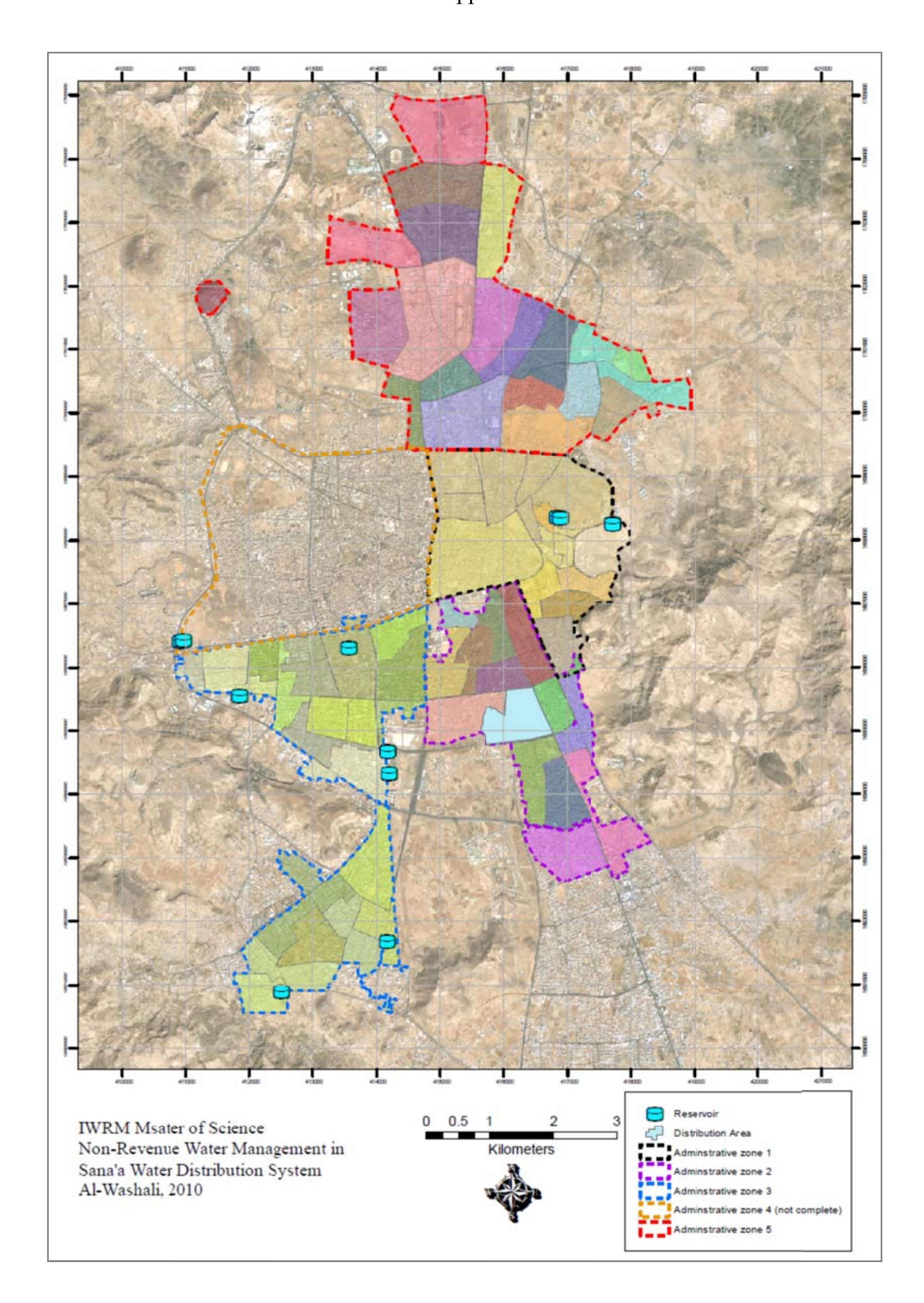
Contrariwise, there are still some specific groups in the other 45% of the city's population that should but not be served by Sana'a water utility (Ministry of Legal Affairs, 2000). Those have other types of problems in having an access to safe and potable water. GTZ (2009, Page 7) highlights that "the access to water in Yemeni urban areas in general is a silent crisis experienced by all, particularly the poor, and tolerated by those who have means." Figure 1.6 is photos showing that poor are the main affected group by the absence of water service in Sana'a city.

1.4.1 Non-Revenue Water in Sana'a Water Distribution System

According to the production and belling data of Sana water utility, SWSLC, (2005-2009), the average annual production of Sana'a water distribution system is 23 MCM

per year with an average Non-Revenue Water of 38% (Figure 1.7). Accordingly, an average of 8.8 MCM per year is NRW of which 50% is physical losses (real losses) and 50% is administrative losses (apparent losses) as expected by Sana'a water utility (SWSLC, 2009b). Hence, the total NRW for the period 2005-2009 is 53 MCM of which 26 MCM is expected to be physical (real) losses.

The annual cost of NRW is high. The average current domestic tariff in Sana water utility is 139 YR. ($0.65 as in December 2010), and the production cost per cubic meter is 69.44 YR. ($0.32) (SWSLC, 2010). Taking into consideration that apparent losses should have the price of water, and real losses should have the cost of water and with the assumption of SWSLC that half of the losses are apparent and the other half are real losses, the cost of the average NRW in Sana water utility, SWSLC, is 916 Million YR. each year ($4.3 Million) with a total of 5.5 Billion YR ($25.6 Million) for the period from 2005-2009.


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Al-Washali, 2010
0 0.5 1 2 3
Kilometers
Reservoir
Distribution Area
Adminstrative zone 1
Adminstrative zone 2
Adminstrative zone 3
Adminstrative zone 4 (not complete)
Adminstrative zone 5

ribution









in Sana'a

Source of

1.5 Problem Statement

Non-Revenue Water's assessment and management in Sana'a water distribution system affect explicitly the sustainability of the water service in the city and implicitly the scarce water resources in the basin.

In Sana'a basin, with a remaining aquifer life around a decade (The World Bank, 2009 and Hellegers, et al, 2008), the average NRW in Sana'a water utility is 8.8 MCM per year. Thus, a proportion of 4.4 MCM of NRW is estimated to be leakages from the water network annually (SWSLC, 2005-2009). Hence, with the safe yield of 50.7 MCM for Sana'a basin (JICA, 2007), the current NRW and leakages proportion of the safe yield of the basin stands at 17.4% and 8.7% successively. Furthermore, if Sana'a water utility, SWSLC, achieves its forth Five-Year Plan for Poverty Alleviation (2010), the utility should sustain 55% of the service coverage. If so, the utility should manage to produce 45 MCM per year. In such a scenario, NRW and leakages from the network with the current average NRW percentage of 38% is estimated at 17.1 and 8.6 MCM per year respectively (SWSLC, 2009b and 2010b). As a result, NRW and water leakages from the network would be 34% and 17% of the basin safe yield successively.

On the other hand, in Sana'a city, with an annual growth rate of 7% (Zeug and Eckert, 2010) and a water service coverage percentage of only 55% (The World Bank, 2009), Sana'a water utility, has general deficiency in its level of service; particularly water quality, water quantity, and pressures in the network (Harza, 2006). In such a context, NRW costs Sana'a water utility 916 Million YR. ($4.3 Million) each year. Consequently, NRW exacerbate the financial and subsequently the technical capabilities of the utility (SWSLC, 2005-2009 and 2010). As a result, a further lowering in the level of service due to NRW level is likely to take place.

In addition, among the other 45% of the city's population that should but not be served by Sana'a water utility (The World Bank, 2009 and Ministry of Legal Affairs, 2000), poor are the main affected segment by the absence of the water service (GTZ, 2009).

1.6 Study importance and Justification

In reference to the above- mentioned context of NRW problem in Sana'a water distribution system, if an efficient NRW management is supplied, the following results could be achieved:

- At the environmental level:

A significant amount of water would be saved. This contributes to prolong the life of the basin and, therefore, participates in Sana'a basin's continuity and sustainability by preventing water wastage of an amount of about 8%-17% of the basin's safe yield. Besides, it minimizes the gap between water demand and water supply in Sana'a basin in general where there is a potential of service expansion.

- At the economic level:

NRW management and reduction would save a considerable amount and cost of either desalinated and/or transported water to Sana'a city according to some future scenarios of water supply in the city (Sufian, et al., 2006).

- At the utility level:
  - Financial benifits: Sana'a water utility, SWSLC, should gain an access to further revenues in self-generated cash flow by means of reducing the production and operation costs; via producing less water with the saved water to meet the same demand. In consequence, it guarantees an access to further capital investments,

maintenance budget, and employees' incentives that have a positive impact on the level of service in general.

- Technical merits: it contributes to more stable supply system which extends the operational age of the network.
- Institutional: it improves the customers service and reduce customer complaints.

- At the societal level:
  - Proper NRW management could save substantial amount of NRW, and as a result, further considerable proportion of the city population shall be covered with the water service. As far as 326.5 thousand further people could be served with water in the current production pattern as the allocated proportion of water per each customer and individual consumer is 480 L/day and 37 L/day respectively (SWSLC, 2009b). Thus, pro-poor water network expansion could be prioritized in order to mitigate the impact of the absence of the water service on the poor segments of Sana'a population.
  - NRW management creates fairness and equity of service among users by means of reducing illegal connections and simultaneously providing the same quality of service for all users since leakages affect the quantity, pressure and quality of the water service.

On the other hand, taking into consideration these dimensions of NRW management, this research tackles the issue of NRW assessment and management in Sana'a water distribution system and potential advantage would be:

- The findings of this research shall help SWSLC to get a deeper understanding of NRW and the breakdown of its components.

- The study would encourage developing a real model of NRW assessment, control, reduction, and management for the water distribution network in Sana'a water utility; SWSLC.
- NRW reduction policies and management options should be suggested in the study in order for Sana'a Water utility, SWSLC, to confront the high percentage of NRW in the network.
- A new International Water Association (IWA) performance Indicator for the physical losses; Infrastructure Leakage Index (ILI) will be introduced first time to the country in general and particularly in Sana'a water utility to allow the comparison of management practices of Sana'a water utility, SWSLC, against NRW with other water utilities in Yemen and other countries in the region.
- The research will contribute to a recent project sponsored by German Agency for Technical Cooperation (GTZ) dealing with NRW as a part of operation and maintenance technical assistance program in Sana'a Water utility; SWSLC.

1.7 Objectives of the study

The objective of this study is to identify the current NRW assessment methods and management policies adopted by Sana'a water utility; SWSLC. Thus, an investigation whether the current NRW management is proactive or reactive in Sana'a water utility will be carried out. Besides, NRW awareness shall be measured among the subjective employees in the NRW-related departments in Sana'a water utility. Afterward, the study aims at identifying NRW volume and breakdown its components (apparent losses, real losses, and unbilled authorized consumption) with respect to water distribution system of Sana'a water utility. And finally, NRW components' prioritization shall be made and management recommendations should be suggested.

In addition, a special focus of an International Water Association "best practice" performance indicator (ILI) will be paid. Accordingly, Infrastructure Leakage Index shall be defined and highlighted for Sana'a water distribution network among other NRW performance indicators. Doing so would introduce and familiarize ILI's application in Yemen as a physical losses performance indicator recommended by the World Bank, American Water Work Association, Environmental Protection Agency and International Water Association (Kingdom et al, 2006, Ranhill and USAID, 2008 and EPA, 2009).

Therefore, the research questions are:

- At what level is the current awareness level of NRW issues of the employees of the NRW-related departments in Sana'a water utility; in its different managerial and operational levels?
- How does Sana'a water utility determine NRW, apparent losses, real losses, and unbilled authorized consumption of its water distribution system?
- What are NRW performance indicators and reduction policies adopted by Sana'a water utility?
- What are the volumes of NRW, real (physical) losses, apparent (administrative) losses, and unbilled authorized consumption for Sana'a water distribution system?
- What is the Infrastructure Leakage Index (ILI), of NRW in the water distribution system in Sana'a water utility?
- What NRW management options and performance indicators should be suitable for the context of Sana'a water utility?

On top of that, this research tries to introduce a suggested novel methodology for NRW assessment and component break down in general.

Chapter 2

Literature Review

2.1 Addressing Non Revenue Water

Real losses (physical losses) and apparent losses (commercial or administrative losses) have synergetic negative impacts on the overall performance of the utility. While real losses cause increase of the operating costs and larger investments, the commercial losses reduce the utility revenues. Ranhill and USAID (2008) have illustrated this detail through drawing vicious and virtuous circles (Figure 2.1). The vicious circle shows that increase NRW level would lead to more production cost and simultaneously less revenues. This, in turn, causes spending the current budget to meet the increase demand on the cost of maintenance of the system. Improper maintenance causes NRW to increase and so forth. The challenge of the water utility is to transform the vicious circle to the virtuous one. Once this is done, reduction in cost, postponing the investments, and more revenues would be accomplished.

2.1.1 Attempts and Failures

Despite the fact that water losses or NRW is a buzzword that always has been targeted in the strategies of water utilities, no satisfactory results have been achieved. An outline for the main points that cause failure for NRW management's attempts could be synthesized from Kingdom, et al. (2006) and Ranhill and USAID (2008) as follows:



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- NRW management requires a long-term commitment and involvement of all water utility departments.
- Successful NRW reduction is not an isolated technical problem, but is linked to overall asset management, operations, customer support, financial allocations, and other factors.
- Politicians and utility managers would rather invest in "visible" new projects than investing in leakage reduction.
- Lack of awareness of NRW's complexity and magnitude or the potential benefits of reducing NRW level.

2.2 Non-Revenue Water Strategizing

The first step when developing a NRW management strategy is setting its long and short-term targets along with the utility's other goals and policies (Ranhill and USAID, 2008). Then Non Revenue Water assessment and components breakdown is the following basic step. The key to progress with the strategy is then to get a better understanding of the reasons for NRW and the factors that influence its components (Kingdom et al, 2006 and Farley and Liemberger, 2004). These starting steps make up the main part of a suggested diagnostic approach for developing NRW reduction strategy by Farely and Trow (2007) which considers the following typical questions:

- How much water is being lost?
- Where is it being lost from?
- Why is it being lost?
- What strategies can be introduced to reduce losses and improve performance?
- How can the strategy be maintained and the achievements sustained?

Details on how to answer these questions are provided in Table 2.1 in which tasks and action plan are presented. Additional issues to be considered when developing the strategy are:

- To estimate the potential saved water by the target period for the various NRW components.
- To carry out a prioritizing analysis according to how the required total reduction can be most cost-effectively achieved; which component to be targeted first or more (Ranhill and USAID, 2008)

- To include the environmental factors into the strategy; which usually is the political role.

nd Trow,

QUESTION	TASK
1. HOW MUCH WATER IS BEING LOST? - Measure components	WATER BALANCE - Improved estimation/measurement techniques - Meter calibration policy - Meter checks - Identify improvements to recording procedures
2. WHERE IS IT BEING LOST FROM? - Quantify leakage - Quantify apparent losses	NETWORK AUDIT - Leakage studies (reservoirs, transmission mains, distribution network) - Operational/customer investigations
3. WHY IS IT BEING LOST? - Conduct network and operational audit	REVIEW OF NETWORK OPERATING PRACTICES - Investigate: historical reasons poor practices quality management procedures poor materials/infrastructure local/political influences cultural/social/financial factors
4. HOW TO IMPROVE PERFORMANCE? - Design a strategy and action plans	UPGRADING AND STRATEGY DEVELOPMENT - Update records systems - Introduce zoning - Introduce leakage monitoring - Address causes of apparent losses - Initiate leak detection/repair policy - design short/medium/long term action plans
5. HOW TO MAINTAIN THE STRATEGY?	POLICY CHANGE, TRAINING AND O&M Training: improve awareness increase motivation transfer skills introduce best practice/technology O&M: Community involvement Water conservation and demand management programmes Action plan recommendations O&M procedures

2.3 Non-Revenue Water Assessment

Non Revenue Water assessment is the first step towards its management, and essential stage when preparing a baseline for NRW strategy (Kingdom, et al., 2006 and Liemberger and Farley, 2004).

The objective of NRW assessment is to quantify NRW amount in the subject system without considering where the losses are actually located (Puust, et al., 2010). Two decades ago, water loss assessment was more a guesstimation process than meticulous science (Liemberger and Farley, 2004). During the last ten years, a large effort has been made by IWA and other organizations to promote new concepts and methods for improving the assessment and management of Non Revenue Water (Vermersch and Rizzo, 2008).

Puust, et al. (2010), in their review paper, concluded that the current leakage, or water losses, assessment methods can be classified into two main groups; (1) top-down assessment methods; using water balance, and (2) bottom-up assessment methods; mainly by using 24 Hour Zone Measurement (HZM), or Minimum Night Flow (MNF) analysis.

2.3.1 Top-Down Approach

The top- down approach, the water balance, was first suggested by IWA Water Loss Task Force as an international "best practice" standard approach for NRW calculations (Figure 1.1-Chapter 1). All definitions of the terms involved in the water balance have been provided clearly with the suggested water balance (Farley and Trow, 2007);. The IWA water balance has rapidly gained international acceptance, and has already been promoted by many International agencies; including AWWA and the World Bank. It has been also adopted by national water utilities, associations, and consultants in the developed, and developing countries (EPA, 2009 and Radivojevic, et al., 2008).

According to the NRW handbook sponsored by Ranhill and USAID (2008), four basic steps have to be made to conduct a water balance:

(1) Determining system input volume

(2) Determining authorized consumption:

- Billed: total volume of water billed by the water utility
- Unbilled: total volume of water provided at no charge; (metered and not metered)

(3) Estimating the apparent (commercial) losses:

- Theft of water and fraud
- Meter under-registration; since the tendency of the customer meters tend to be under-registration than over-registration (AWWA, 2009)
- Data handling errors

(4) Calculating the real (physical) losses:

- Leakage on transmission mains
- Leakage on distribution mains
- Leakage from reservoirs and overflows
- Leakage on customer service connections

According to these steps, system input volume, billed consumption, and unbilled metered authorized consumption are usually metered. In contrast, unbilled authorized unmetered consumption and the apparent losses are estimated.

The unbilled authorized consumption (metered and unmetered) is usually a small component, and thus typically assumed in the range from 0.5% (Lambert and Taylor, 2010) to 1.25% (AWWA, 2009) of the system input volume or estimated by the utility as it is site- specific.

On the other hand, the apparent losses estimation starts with assuming the unauthorized consumption at 0.25% as in (AWWA, 2009) or 1% as in (Lambert and Taylor, 2010). Alternatively, it could also be estimated via the utility's experience with validated data (AWWA, 2009). Afterwards, the customer meter inaccuracies should be estimated according to meter tests at different flow rates representing typical customer water use and meter guidance manuals as well (Mutikanga, et al., 2010; Ranhill and USAID, 2008; and AWWA, 2009). The next step is to estimate systematic data handling errors by exporting and analyzing historic billing data trends for a certain period (Mutikanga, et al., 2010 and Ranhill and USAID, 2008). Thenceforth, the apparent losses component is estimated by summing its subcomponents.

Eventually, the real (physical) losses are calculated by subtracting the apparent losses and authorized unbilled consumption from the volume of NRW. Hence, NRW components are quantified by the water balance; top-down approach.

2.3.1.1 Unauthorized Consumption Estimation

Tackling the unauthorized consumption issue, it is rather difficult and challenging to estimate the unauthorized consumption (Mutikanga, et al., 2010) due to its hidden nature. The NRW handbook (Ranhill and USAID, 2008) confines this point by recommending that the unauthorized estimation should be a transparent component-based process (Ranhill and USAID, 2008). The guidance manual of Control and Mitigation of Drinking Water Losses in Distribution Systems published by the Environmental Protection Agency (2009) emphasized the difficulty of estimating unauthorized consumption, but has only recommended that it must be accounted (EPA, 2009).

Mutikanga, et al. (2010) has attempted to estimate unauthorized consumption through long awareness and rewarding program. Advertisements were placed in the local newspapers requesting anyone with information on illegal use to report it to the utility

and a cash reward was offered (Mutikanga, et al., 2010). This process, however, is considered bottom-up auditing rather than top down approach (Mutikanga, et al., 2010). Besides, there still might be potential significant illegal connections that are not reported.

To sum up this matter , yet, there is still lack of scientific methods attempts to quantifying the unauthorized consumption through top down approach apart from assuming it from 0.25% - 1% of the system input volume.

2.3.2 Bottom-Up Approach

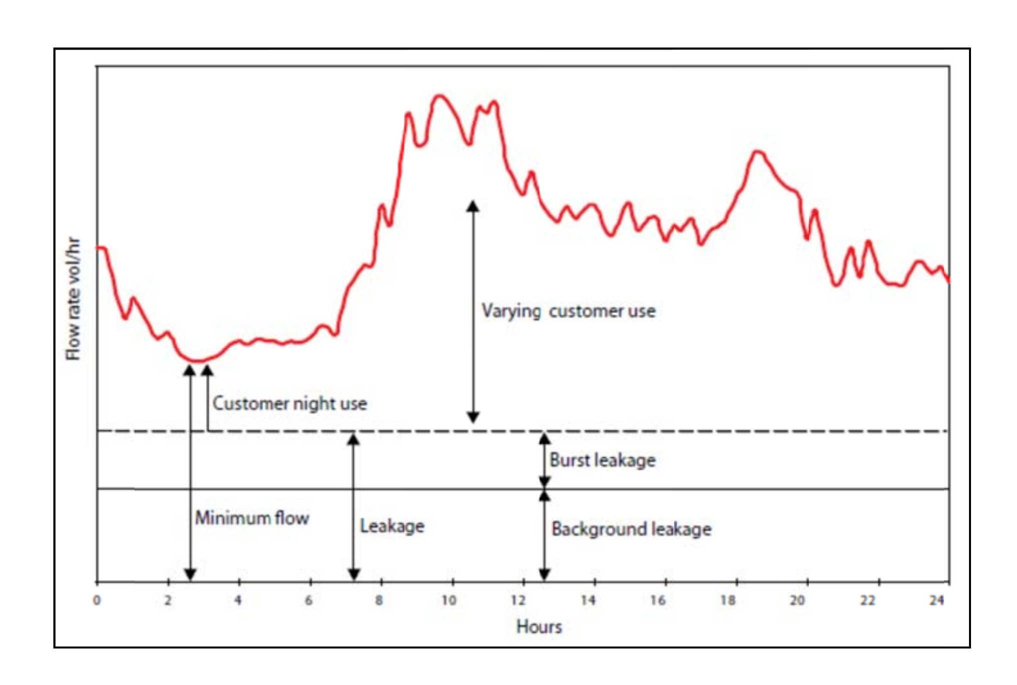
Bottom-up approach estimates the physical losses by analyzing 24 Hour Zone Measurement (HZM) or Minimum Night Flow (MNF) analysis. Minimum Night Flow analysis is more common since the HZM in principle is used eventually to apply MNF analysis approach (Puust, et al., 2010).

Minimum Night Flow analysis is the lowest flow into the District Metered Area[2] (DMA) over a 24-hour period, which generally occurs at night when most consumers are inactive as shown in Figure 2.2 (Farley and Trow, 2007). Minimum Night Flow analysis requires DMA, and to perform field tests between 02: 00 am and 04: 00 am in which most users do not use water (Cheung, et al., 2010 and Farley and Trow, 2007). Besides, Minimum Night Flow analysis entails identifying in advance the potential large nightly water consumers within the DMA, and further, the medium water pressure in the DMA network (Cheung, et al., 2010 and Puust, et al., 2010)

Accordingly, estimating the leakages in the MNF period is carried out by subtracting legitimate night uses from the MNF (Farley and Trow, 2007).

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2 District Metered Area is a discrete zone with a permanent boundary defined by flow meters and/or closed valves. For further information on designing and implementing the DMA, see Farley and Trow (2007).


Flow rate vol/hr
Varying customer use
Customer night use
Burst leakage
Minimum flow
Leakage
Background leakage
0
2
4
6
8
10
12
14
16
18
20
22
24
Hours

. USAID

2.3.2.1. Leakage Modeling; Pressure-Leakage Relationship

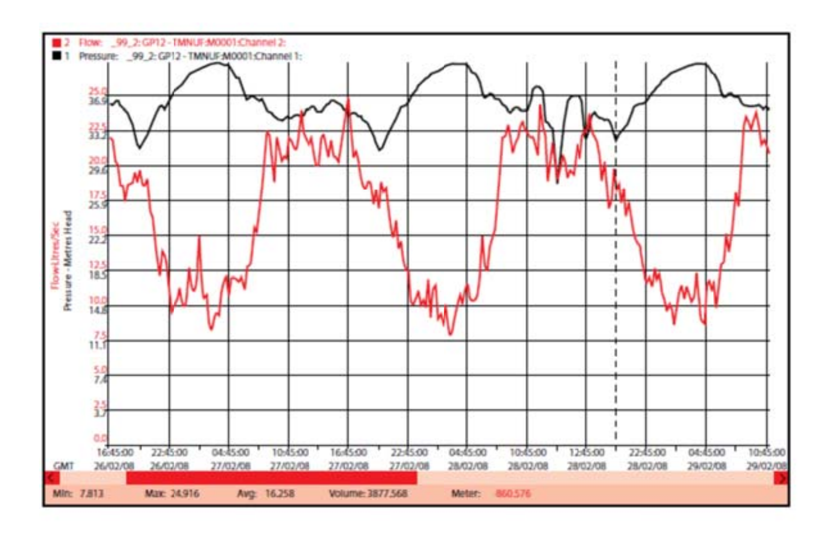
Estimating night leakages through MNF is eventually calculated as shown in the previous section. However, daily leakage estimation still needs considering the pressure-leakage relationship. Leakage volume is a function of the pressure in the system. In sequence, average pressure in the DMA will change over a 24-hour period depending on the pressure pattern. Therefore, when the DMA has its lowest inflows, the pressure is at its highest as shown in Figure 2.3 (Ranhill and USAID, 2008). Therefore, Lambert (2001) suggests using a method called Fixed and Variable Area Discharges (FAVAD) (Lambert, 2001as cited in Puust, et al., 2010). The increase or decrease of real losses due to a change in pressure can be computed by FAVAD concept, after intensive experiments and efforts to simplify the concept, according to the following equation:

$L1/L0 = (P1/P0)^{N1}$ …………………………………………...Eq.2.1

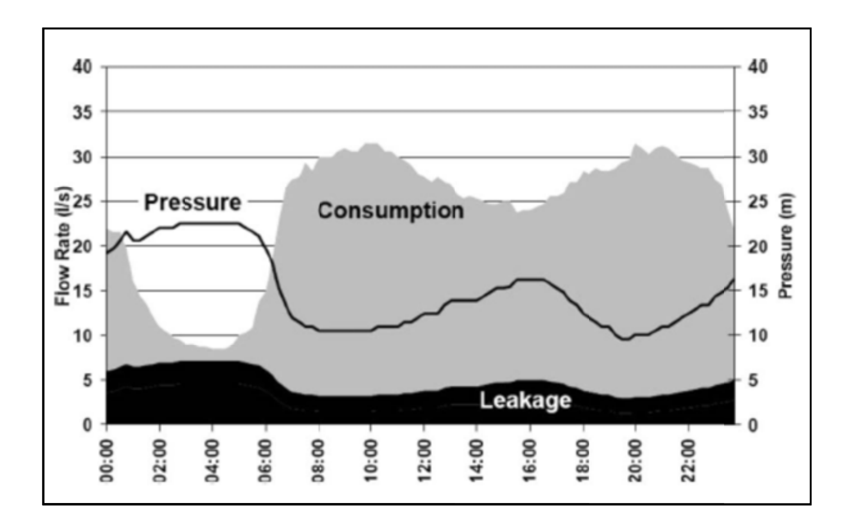
Where L: Leakage; P: pressure; and N: leakage exponent

Leak exponent, N, varies from 0.5-1.5; being close to 0.5 with fixed area leakage path and 1.5 with variable leakage path. Fixed area leakage is usually occurs on rigid pipe materials and variable area leak occurs on flexible pipe materials such as Pvc or Polyethylene which can split, and where the area of the split also varies with the pressure. Accordingly, N exponent is 0.5 for rigid pipes and 1.5 for flexible pipes and in between with mixed pipes network (Puust, et al., 2010 and Lambert, personal communication, 2010).

After estimating the night leakages by subtracting legitimate night uses from the MNF, daily leakages estimation is the next step. To get a satisfying estimate of the daily leakage, the pressure leakage relationship should be modeled as in Figure 2.4, and then FAVAD concept should be applied to simulate and quantify the daily real losses of the DMA.



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. Source:

2.3.3 A component Base Analysis

This approach uses the concept of Burst And Background Estimates (BABE) that was developed by Lambert in the 1990s (EPA, 2009). The underlying principle of BABE concept is that real losses consist of numerous leakage events. Loss volume for each event is a function of the average flow rates and average run-times for different types of leakages (Thornton, et al., 2008) (Figure 2.5). Therefore, to conduct such analysis, real losses in the network is categorized into four categories; (1) Background leakage at joints and fittings; (2) Reported leaks and bursts (high flow rates with short duration); (3) Unreported leaks and bursts (moderate flow rates with duration depending on the method of active leakage control); and (4) Hidden loss or excess losses; flow rates too low to be detected by sonic detection devices (EPA, 2009).

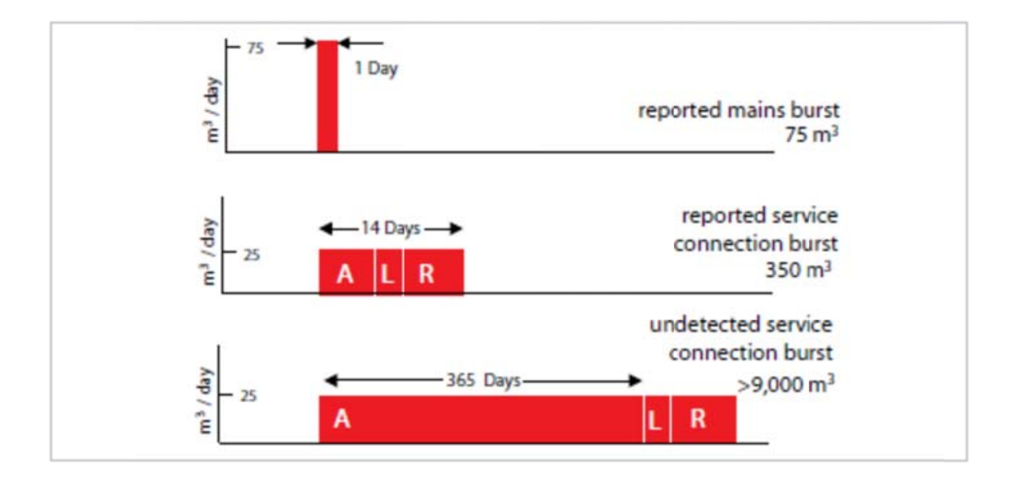


Figure 2.5: Leak run time and volume of water loss: A: Awareness Time; L: Locating Time; R: Repairing Time. Source: Ranhill and USAID (2008)

In using BABE model, typical burst flow rates are already set at a standard pressure, and then are adjusted to actual pressure using appropriate assumptions for FAVAD principle (EPA, 2009). Table 2.2 provides the standard approximate flow rates for the reported, unreported and background losses.

Table.2.2: Standard Flow Rates for the BABE Method Source: IWA Water Loss Task Force as cited in Ranhill and USAID, (2008)

Reported and Unreported Bursts Flow Rates		
Location of Burst	**Flow Rate for Reported Bursts [l/hour/m pressure]**	**Flow Rate for Unreported Bursts [l/hour/m pressure]**
Mains	240	120
Service Connection	32	32
Background Losses Flow Rates		
Location of Background Loss	**Flow Rate of Background Loss [Liter]**	**Unit of Measure**
Mains	9.6	Liters per km of mains per day per meter of pressure
Service Connection – main to property boundary	240	Liters per service connection per day per meter of pressure
Service Connection – property boundary to customer meter	32	Liters per km of service connection per day per meter of pressure

Although this concept is the first one to model physical losses objectively rather than empirically (Ranhill and USAID, 2008), Puust, et al. (2010) did not go through this concept in their recent review paper of real losses assessment methods. This might be due to its excessively estimation-oriented approach. Thornton, et al. (2008) has also recommended not using the component analysis, BABE, on its own to estimate the real losses because of significant level of uncertainty in much of the data used in the analysis. Although BABE approach has significant level of uncertainty in much of the data used, it provides valuable data for further break down the real losses into subcomponents, and thus, these data could be utilized for designing the appropriate leakage reduction policy (Thornton, et al., 2008).

2.3.4 Synergetic Approach

It is strongly recommended with a consensus in the literature that combining the top down approach with the bottom up approach would enhance the accuracy of the NRW assessment and thus provides satisfactory results (Thornton, et al., 2008; Ranhill and USAID, 2008; EPA, 2009; Lambert and Taylor, 2010; and Puust, et al., 2010). Furthermore, when top down approach is already conducted, it is also recommended using BABE concept as a supplementary analysis for the top down water balance (EPA, 2009 and Thornton, et al., 2008). Doing so allows quantifying the hidden losses[3] and thus, redesigning an effective leakage prioritizing and reduction policy.

2.4 Monitoring NRW Management

Non Revenue Water is a measure of a utility's efficiency; in terms of both operational performance and financial performance. Performance indicators (PIs) of NRW are usually used to rank the water utility's performance against other water utilities in the country or in the regional level (Ranhill and USAID, 2008). Perhaps the most common one is NRW as a percentage of the system input volume; however, there are other NRW PIs that are used for managerial and operational monitoring.

2.4.1 Performance Indicators

Before an international report for performance indicator for NRW in 2002, several countries have had their own indicators (Lambert, 2002). Using these indicators, the

[3]Hidden loss or Excess Losses are losses include water lost from leaks that are not detected and repaired under the current leakage control policy (Thornton, et al., 2008). Excess Losses can be calculated from the following equation: Excess Losses = Physical losses from water balance - known physical loss components.

comparison of performance from utility to utility was based on the different methods for determining these indicators. For example, the following PIs were adopted:

percentage of average daily flow was:	USA, France;
M^3/km of mains/hours:	German, Japan;
liters/property/hour:	UK

Two problems were associated with these indicators: first, they do not consider component analysis techniques (Puust, et al., 2010). Second, all of them were based on the term Unaccounted For Water (UFW). Unaccounted For Water, in turn, was widely used, but misinterpreted and manipulated in a way that made it difficult to be compared in the international level (Mckenzie and Lambert, 2004). This conclusion was made in the international report made in 2001 (Lambert, 2002) when data of UFW from 22 countries were compared and analyzed. For these reasons the term NRW among a package of standard "best practice" performance indicators were introduced (Table2.3) by IWA with standard and unambiguous definitions in order to allow performance comparison in the national and international level (Mckenzie and Lambert, 2004).

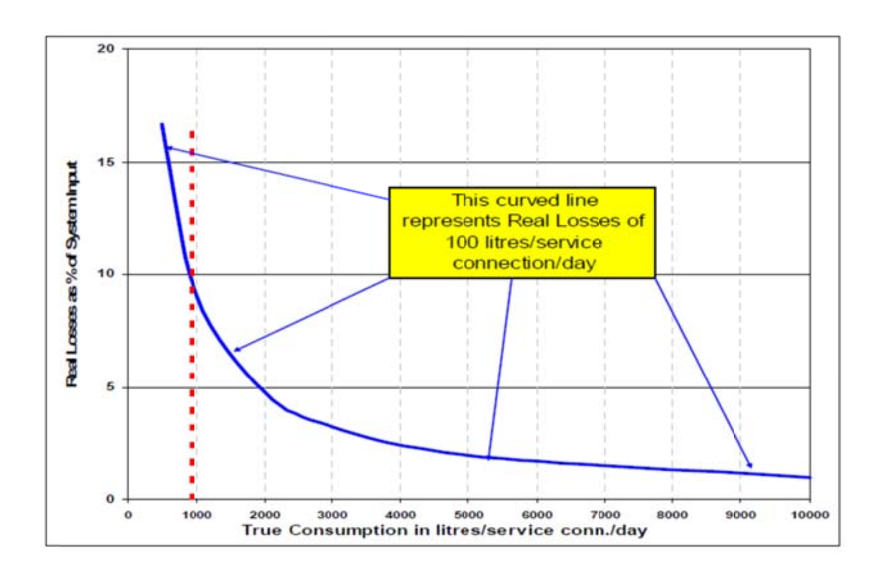
(2010)

Function	Level	Performance Indicator	Comments
Financial: NRW by Volume	**1** (Basic)	Volume of NRW **[% of System Input Volume]**	Can be calculated from simple water balance, not too meaningful
Operational: Apparent Losses	**1** (Basic)	**[m3/service connection/year]** or: **[m3/km of mains/year]** (only if service connection density is <20/m)	Best of the simple 'traditional' performance indicators, useful for targer setting, limited use for comparisons between systems
Operational: Real Losses	**1** (Basic)	**[litres/service connection/day]** or: **[litres/km of mains/day]** (only if service connection density is <20/km)	
Operational: Real Losses	**2** (Intermed.)	**[litres/service connection/day/m pressure]** or: **[litres/km of mains day/m pressure]** (only if service connection density is <20/km)	Easy to calculate indicator if the ILI is not known yet, useful for comparisons between systems
Financial: NRW by cost	**3** (Detailed)	Value of NRW **[% of annual cost of running system]**	Allows different unit costs for NRW components, good financial indicator
Operational: Real Losses	3 (Detailed)	**Infrastructure Leakage Index (ILI)**	Ratio of Current Annual Real Losses to Unavoidable Annual Real Losses, most powerful indicator for comparisons between systems

2.4.2 Percentage as a Performance Indicator

Despite the fact that percentage is the most common performance indicator for NRW, it is heavily influenced by consumption and does not indicate the real level of leakage in the network (AWWA, 2009).

As shown in Figure 2.6, when the real losses are 100 L/service connection/day, the NRW level percentage will vary from 17% for system with low water consumption to 1% with system with high water consumption (Lambert and Taylor, 2010). This implies that when utilities with intermittent supply decrease their water production due deficiency, the NRW level will decrease showing a progress in the utility performance. Therefore, the call for neither using NRW as a performance indicator for real losses nor for NRW has been increased.



ed.

Nonetheless, NRW as a percentage of system input volume could be useful for its "shock value" as high percentage that could encourage the utility to further investigate and initiate NRW management strategy (Ranhill and USAID, 2008).

2.4.3 Infrastructure Leakage Index

The most commonly used leak index nowadays is Infrastructure Leakage Index (ILI) (Puus, et al., 2010). It is recommended by EPA (2009), AWWA (2009), and IWA (2007). The ILI is a good indicator of physical losses for that it takes into account how the network is managed and thus, it is a measure of how well a distribution network is managed under the current operating conditions (Ranhill and USAID, 2008). ILI implicates the fact that real losses will always exists, even in the very best and well managed distribution system (Winarni, 2009). As illustrated in Figure 2.7, real losses could be reduced by good management to certain extent where the real losses is unavoidable.

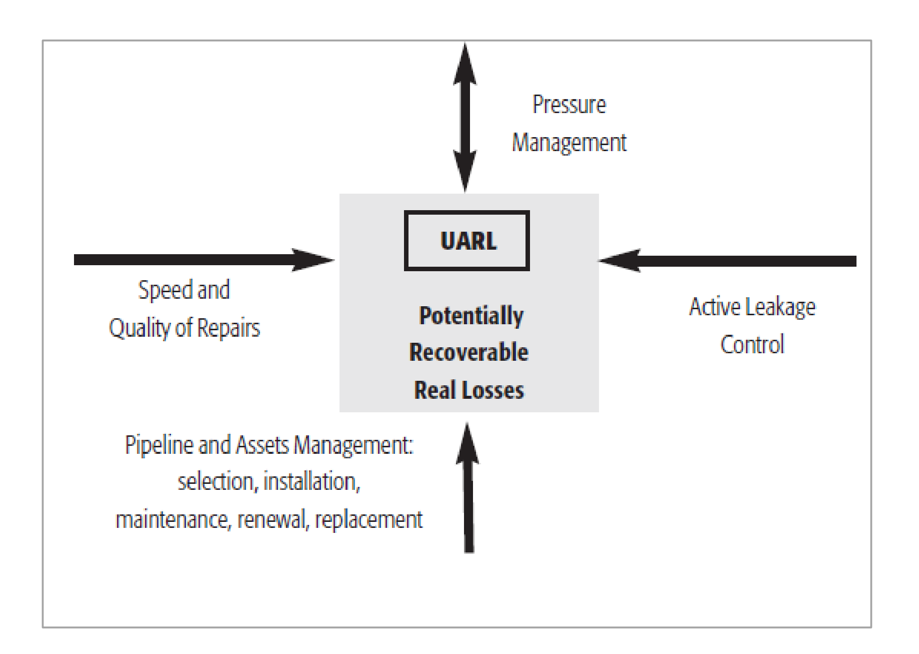


Figure 2.7: The Unavoidable Annual Real Losses concept. Source: Lambert, 2003

The ILI is unitless and therefore, allows easier comparisons between utilities within the country or the region level with no need for units' conversion. Nevertheless, it is worth mentioning that the main limitation of ILI is being a technical indicator that does not take into account the relative economic aspects such as the costs of leakage

management (Puust, et al., 2010). In spite of that, it is still considered the most robust and common indicator that yet has no substitute for the physical losses.

Infrastructure Leakage Index is the ratio of the Current Annual Real (physical) Losses (CARL) to the Unavoidable Annual Real Losses (UARL) as shown in Equation 2.2 and Equation 2.3:

ILI = CARL/ UARL ………………………………………...Eq.2.2

UARL (liters/day) = (18 x Lm + 0.8 x Nc + 25 x Lp) x P……..Eq.2.3

Where

CARL = Current annual real losses

UARL= Unavoidable annual real losses

Lm = Mains pipes length (km);

Nc = Number of service connections;

Lp = Total length of private pipe, property boundary to customer meter (km);

P = Average pressure (m)

It was recommended by the developers of this equation that for the equation to give a true value, it should be applied for any system with more than 5000 service connections, service connection density greater than 20 per km mains, and operating pressure more than 25 m (Winarni, 2009). With more following researches, a lower limit for number of service connections was set as 3000, and the lower limit on density of connections has been removed (Thornton and Lambert, 2005). In contrast, Liemberger and McKenzie (2005), through analyzing many case studies, have found that the equation provides a useful indication of high leakage even when used outside the normally accepted limits. Nevertheless, further efforts have been made in order for this equation to work in the systems with low pressure. Thornton and Lambert (2005) worked on developing a correction coefficient for the equation. The coefficient Cp was introduced to the equation, and can be assessed based on the types of the pipes material in the

network as a percentage of rigid and flexible pipes. Accordingly, Figure 2.8 is used to estimate the value of Cp and thus, Equation 2.3 will be as follows:

UARL (liters/day) = (18 x Lm + 0.8 x Nc + 25 x Lp) x P x Cp ………..Eq.2.4

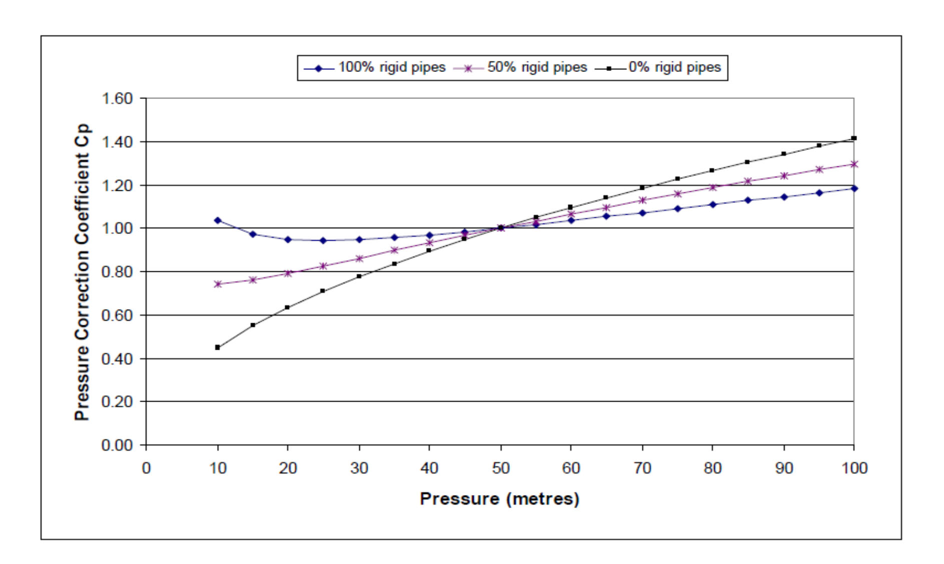


Figure 2.8: Provisional relationship between pressure and Cp, for systems with different % of rigid pipes. Source: Thornton and Lambert, 2005

Although the ILI is the most common and robust indicator for the physical losses, its main limitation is being technical indicator that does not consider the relative costs of leakage management (Puus, et al., 2010). Besides, introducing it to the developing countries associate many accuracy matters. Liemberger and McKenzie (2005) have discussed the accumulation of the calculation's inaccuracies in the final value of ILI; however, they highlighted that it is still the most suitable indicator for water utilities in developing countries.

All the elements of Equation 2.4 should, theoretically, be defined straightforward for any water system; however, when calculating the UARL, it should be adjusted for the intermittent supply by dividing UARL by the average number of supply hours per day (Ranhill and USAID, 2008). Besides, Lp which is basically the total length of private pipe; property boundary to customer meter is different from system to system. Appendix.1 provides different charts for defining the Lp in the water systems.

Once the ILI is defined, it could be compared to the expected level of real losses with the assessment matrix for the real losses suggested by the World Bank Institute (Table 2.4). The matrix has the real losses in liter/connection/day in different pressure levels.

Table 2.4: Real Loss Assessment Matrix. Source: World Bank Institute, 2009

Technical Performance Category		ILI	Liters/connection/day (when the system is pressurized) at an average pressure of:				
			10 m	20 m	30 m	40 m	50 m
Developed Country Situation	A	1 - 2		< 50	< 75	< 100	< 125
	B	2 - 4		50-100	75-150	100-200	125-250
	C	4 - 8		100-200	150-300	200-400	250-500
	D	> 8		> 200	> 300	> 400	> 500
Developing Country Situation	A	1 - 4	< 50	< 100	< 150	< 200	< 250
	B	4 - 8	50-100	100-200	150-300	200-400	250-500
	C	8 - 16	100-200	200-400	300-600	400-800	500-1000
	D	> 16	> 200	> 400	> 600	> 800	> 1000

Where;

Category A: Good; further loss reduction may be uneconomic and careful analysis needed to identify cost-effective improvements.

Category B: Potential for marked improvements: consider pressure management, better active leakage control, and better maintenance.

Category C: Poor; tolerable only if water is plentiful and cheap, and even then intensify NRW reduction efforts.

Category D: Bad; the utility is using resources inefficiently and NRW reduction programs are imperative (World Bank Institute, 2009).

The matrix is divided into two groups; the developed and developing countries. This artificial spilt, according to Kingdom et al, (2006), is due to the gap in performance between water utilities in the developing and developed countries. Setting targets for water utilities in the developing countries based on the performance of the best utilities in the developed countries would be unrealistic and thus, counterproductive.

Chapter 3

Suggested Approach for NRW Assessment

3.1 The Underlying Principle

The principle of this approach is that tracking water to its destiny confirms that after water is used in the premises, only the real consumption enters the sewer networks. This includes water used through illegal connections and bypasses. Besides, meter inaccuracies that appear in the billing system of the water utilities do not appear in the sewers flow. In other words, the apparent (administrative) losses should appear in the outlet of the wastewater network of the District Metered Area or the inlet of the wastewater treatment plant. Unambiguously, the wastewater treatment plant receives the apparent losses but not the real losses. The same applies with the out let of a certain zone or DMA. Hence, studying the wastewater flow would indicate the quantity of the apparent losses.

3. 2 The Reverse Approach Equation

The methodology tries to draw the line between apparent losses and real losses in NRW calculations by utilizing the fact that apparent losses enter the wastewater sewers while

real losses don't. Accordingly, quantifying the apparent losses is done by studying the inflows' measurements of the wastewater treatment plants or the sewers' outlet flow of the DMA. Hence, the apparent losses could be estimated through Equation 3.5 that is developed from the following equations:

*NRW= Apparent losses+ Real Losses + Unbilled Authorized Consumptio*n………....Eq.3.1

NRW = Produced water – Billed Water Consumption…………….……………..……Eq.3.2

Produced Water = Real Losses + Outdoor Use Consumption + Wastewater Plant Inflow + Sewers Exfiltration **-** *Sewers Infiltration*……………………………………………Eq.3.3

When applying 3 into 2;

NRW= Real Losses + Outdoor Use Consumption + Wastewater Plant Inflow + Sewers Exfiltration **-** *Sewers Infiltration – Billed Water Consumption*……………...……...Eq.3.4

With applying 1 into 4;

Apparent losses = WWTP Inflow – Billed Water Consumption – Unbilled Authorized Consumption + Outdoor Use Consumption + Exfiltration – Infiltration…...………...Eq.3.5a

Or ***Qa = Qww – Qbw – Quac + Qout + Qex – Qin***………………….………....**Eq.3.5b**

Whereas:

Qa*:* Apparent losses

Qww: Inflow of the wastewater treatment plant or the flow in the sewers' outlet of a DMA.

Qbw:Billed water consumption; all metered consumption which is billed.

Quac: Unbilled authorized consumption; metered consumption which is unbilled as well as any kind of authorized consumption that is neither billed nor metered.

Qout: Outdoor use consumption; water used for lawn irrigation or watering of planted, car washing, house cleaning, and refilling of ornamental fountains, ponds and surface lagoons (Núñez, et al., 2010).

Qex: Exfiltration; wastewater flow that exfiltrates out of the sewers.

Qin: Infiltration; groundwater that enters the sewer system.

3. 3 Determining the Components of the Equation

Qww and Qbw; the wastewater flow and billed water consumption are measured and thus, they have usually available data in water utilities.

Quac; unbilled authorized consumption is usually a small component in the equation. It is either assumed, as in the other NRW assessment methods, from 0.5% (Lambert and Taylor, 2010) to 1.25% (AWWA, 2009) of system input volume, or estimated by the utility as it is site-specific.

Qout; outdoor use consumption, could be calculated through Winter Summer Method or Minimum Month Method by studying the variance of water consumption's monthly data for one year (Gleick, et al., 2003). So, it needs only the monthly consumption data of the studied city for one year.

Qex and Qin: Exfiltration from, and Infiltration to sewers could be calculated from Equation 3.6 that is adapted from Rutsch, et al., (2008) and Amick, et al., (2000) for the exfiltration; and De Bénédittis and Bertrand-Krajewski, (2004) and Dublin Drainage Consultancy, (2001) for the infiltration:

Exfiltration – Infiltration = wastewater generated at the demand site - wastewater volume at the entrance to the WWTP……………………………………………Eq.3.6a Or

$Qex\text{-}Qinf = Np \cdot Qcap \cdot (1\text{-} Qout\%) + Qind - Qww$………………………………… Eq.3. 6b

Where;

Qex: Exfiltration

Qinf: Infiltration

Np: Nr. of population served

Qcap: per capita water consumption

Qout%: outdoor use percentage from water consumption

Qind: Industrial wastewater discharge

Qww: WWTP inflow[4]

---

[4]- Industrial wastewater discharge could be estimated straightforward from the records of the billing system in the water utility.

- WWTP inflow should be of dry-weather flow and does not include flow caused by rainfall.
- Per capita consumption should be measured. It should not include any losses.

However, Infiltration should be zero for sewers with far enough ground water table and when there is no inflow caused by rainstorm (in the dry seasons). In this case, there are other methods for assessing the exfiltration rate. Rutsch, et al.(2008), in their review paper, has presented a thorough analysis for these methods and their accuracies. For a "snapshot" apparent losses assessment, exfiltration could be assumed from 5%- 10% of the base flow. This assumption was a conclusion of experimental studies of sewer exfiltration conducted by Ellis, et al. (2003) so they pointed out that exfiltration from urban sewers can be estimated as being probably no more than 5% - 10% of average daily dry weather (base wastewater) flow .

3.3.1 Estimation of Outdoor Use Consumption

Outdoor residential water use consists of water used for lawn irrigation or watering of planted, car washing, house cleaning, and refilling of fountains, ponds and surface lagoons(Núñez, et al., 2010).

The outdoor use consumption could be estimated by using variables that reflect the outdoor characteristics such as irrigable area of the premises, garden sizes, and pool ownership (Arbués, et al., 2003). Interestingly, the amount of water used for irrigation purposes is the dominant proportion of outdoor use (Singh, et al, 2009; Palenchar, et al., 2009; and Gleick, et al., 2003). Mitchell, et al. (1999), estimate Garden irrigation at 90% of the outdoor water use. As reported by Gleick, et al., (2003), Skeel and Lucas (1998) found that outdoor water use for single family house accounted more than 95 percent of the observed increase in peak summer consumption. 85% of this increase was because of irrigation uses and less than 5% was due to a slight increase of the indoor use in summer months. Hence, the climatic conditions' variance influences the outdoor irrigation and therefore, the outdoor water demand (Mitchell, et al., 1999). For this

reason, the methods of estimating the outdoor water use are based on the conclusion that irrigation areas of the premises makes up the almost all proportion of the outdoor water use.

There are three methods for calculating the outdoor use consumption; summer winter method, minimum month method, and average winter month method (Gleick, et al., 2003). Summer winter method (or average winter consumption method) relies on the assumption that the difference between winter use and summer use was approximately equal to outdoor use (Romero and Dukes, 2010 and Gleick, et al., 2003).

Alternatively, the minimum month method is the most popular way for calculating the outdoor water use (Palenchar, et al., 2009). It assumes that the lowest-use month represents indoor use and all differences between the other months and the minimum month consumption were considered to be outdoor use (Romero and Dukes, 2010). The third method, average month method, is adapted from minimum month method approach through using the average of the three lowest water use months rather than the minimum month to represent the indoor water use (Gleick, et al., 2003).

3.4. Advantages of the Approach

- The reveres approach provides a substitute for the top-down approach in the developing countries where unauthorized consumption should not be assumed ≤ 1% of the system input volume. In contrast, unauthorized consumption could reach as high as 10% of the system input volume in the developing countries (Mutikanga, et al., 2010).
- This methodology uses already available data that are usually existed in the water utilities.

- The approach has the advantage of being more cost-effective over the bottom-up approach which, in turn, is cost and time-consuming for that it depends on field experiments. Furthermore, when conducting bottom-up approach, DMA representativeness is questionable especially when the DMA itself has many requirements to be fulfilled (Farley and Tow, 2007).
- Unlike the other existed approaches, the suggested approach could be used to breakdown the components of apparent losses and come up with objective estimation of the unauthorized consumption.

3.5. Limitation

This methodology should work under the following conditions:

- Data to be used in this methodology should be for dry seasons. Data of WWTP for dry days throughout the year should supply the average dry flow for the whole year.
- Hydrants, firefighting and public water use should be minimized, null, or considered. However, controlling the public use for a certain period could be achieved through many ways. For, example by labeling the hydrants of the public use in the DMA, and then checking how many were used, if any, and then estimating this quantity.

3.6. Feedback

This approach was discussed with three NRW experts in the International Water Association. Their feedback was considered to further considerations when developing

the approach. Afterward, it was sent again with an example to Mr. Allan Lambert[5], for further discussion about the methodology. Eventually, an initial software has been developed for this approach (Figure 3.1).

Colour Coding of Cells	Data entry	Calculated values	Taken from another cell	Defaults	Worksheet, "Calculated values' and 'Taken from Another Cell' are protected without a password

Water Utility	XYZ Utility	Mains Length		km	Draft Version 1a by A Lambert 3rd
System	Anytown	Service Connections		number	Taha - if you can fill in typical infrastructure details on Rows 4 to 8 then IWA Performance indicators can be calculated
		Connection Density	#DIV/0!	per km of mains	
		Customer meters are located		metres after property line	
		Average System Pressure		metres	

Calculation without use of Confidence | > Calculation with confidence limits added

WATER BALANCE	Volume	95% Conf limits	Standard Deviation	Variance $=SD^2$	Notes and comments by AL
	CM/day	+/-%	CM/day		
Water Supplied	60000	2.0%	612	374844	+/- 2% is about the best accuracy to be expected from bulk meters with independent
Billed Metered Consumption	34860	2.0%	356	126533	If population 420000 at 83.0 litres/head/day, then Billed Consumption = 34860
Non-Revenue Water	25140	5.5%	708	501376	
Unbilled Authorised	249	25.0%	32	1011	Estimated as 0.715% of Billed Consumption 249 CM/day but could be +/- 25%?
Water Losses (Real + Apparent)	24891	5.6%	709	502387	

APPARENT LOSSES BALANCE	Volume	95% Conf limits	Standard Deviation	Variance $=SD^2$	Notes and comments by AL
	CM/day	+/-%	CM/day		
WWTP Inflow	38000	5%	969	939713	WWTP inflows in open channels are more difficult to measure reliably than metered
Billed Metered Consumption	34860	2.0%	356	126533	
Unbilled Authorised	249	25.0%	32	1011	
Outdoor consumption	1743	50%	445	197707	Estimated as 5.00% of Billed Consumption 1743 CM/day but could be +/- 50%?
Exfiltration	1760	50%	449	201537	Estimated as 7.00% of Billed Consumption 1760 CM/day but could be +/- 50%?
Infiltration	0	0%	0	0	Estimated as ?
Apparent Losses	6394	37.1%	1211	1466500	AL Confidence limits v.sensitive to Billed Consumption (many parameters estimated from

Lambert

3.7. Example

Water produced; System input volume = 60000 CM/day

Billed consumption= 35000 CM/day … Means NRW= 42%

Unbilled authorized consumption= 300 CM/day

The service is covered 24/7, and the coverage service of water and wastewater is 100%

The inflow of the WWTP= 38000 CM/day

Population served = 420 000 people

Water consumption = 100 L/day.cap

[5]Mr. Allan Lambert is the developer of BABE, FAVAD and ILI concepts in the discipline of Non-Revenue Water management.

In this example the previous outdoor use studies estimated it as 5% or assumed based on behavior of people, gardens areas, and car washing practices. Exfiltration is assumed 7%.

So: Outdoor use = 0.05*420 000* 100/ 1000 = 2100 CM/day

Exfiltration is assumed to be 7% = 0.07 * (420 000 * 100 */ 1000 - 2100) = 2793 CM/day

Therefore: The apparent losses = WWTP Flow – Billed consumption – unbilled authorized consumption + outdoor use + Exfiltration

Then apparent losses = 38000 – 35000 – 300 + 2100 + 2793 = 7593 CM/day

Then, real losses = NRW- apparent losses – unbilled authorized consumption = 17107 CM/day

Therefore:

The apparent losses are 30% of NRW (13% of the system input volume).

The real losses are 68% of NRW (28.5% of the system input volume)

The unbilled authorized consumption is 2% of NRW (0.5% of the system input volume)

Chapter 4

Non-Revenue Water Assessment in Sana'a Water Utility

4.1 Introduction

This chapter discusses why the suggested approach was used for NRW assessment in Sana'a water distribution system. Afterwards, thorough and detailed methods for calculating the volumes of different NRW components are presented in this chapter to serve as a case study for implementing the suggested approach. NRW software were used to visualize the results of the assessment and integrate the results in a form of the standard water balance and calculate the cost of NRW. At the end of this chapter, results of the assessment are discussed and conclusions are drawn.

4.2 Research Question

- What are the volumes of NRW, real (physical) losses, apparent (administrative) losses, and unbilled authorized consumption for Sana'a water distribution system?

4.3 Research Method

This section demonstrates why all the existed methods of NRW assessment do not give satisfactory results when applying them for the case of Sana'a water distribution system. Afterwards, the suggested approach in chapter three will be implemented with a slight modification.

4.3.1 Appropriateness of Applying the Existing Methods

4.3.1.1 Top Down Approach

As presented in Chapter 2, top down approach tries to estimate the apparent losses and unbilled authorized consumption first, and then, it calculates the real losses. In the estimation of the apparent losses, unauthorized consumption is assumed from 0.25% - 1% of the system input volume.

This assumption is inappropriate neither in the case of Sana'a water network nor in developing countries in general because the volume of unauthorized consumption is likely to be higher than the volume calculated by this assumption. Mutikanga, et al. (2010) concludes that unauthorized consumption in the developing countries might reach as high as 10% of water sales (6% of the system input volume in Sana'a case with average NRW of 38%). Besides, Sana'a water utility, SWSLC, estimates apparent losses from 19% - 23% of the system input volume of which a considerable amount to be unauthorized consumption.

Therefore, applying the top-down approach should not represent the real trends of NRW components because of the very little assumption of unauthorized consumption that does not fit Sana'a case. Further, assuming the value of unauthorized consumption does not help Sana'a water utility to design the appropriate prioritizing and reduction policies for the apparent losses based on the component-base analysis.

Henceforth, top down approach with its assumption of unauthorized consumption from 0.25% - 1% of the system input volume is not an appropriate method for NRW assessment in Sana'a water distribution system.

4.3.1.2 Bottom Up approach

Bottom up approach uses Minimum Night Flow (MNF) analysis. This in turn, requires performing field tests between 02: 00 am and 04: 00 am in which most users do not use water, and then the leakages in the MNF period is carried out by subtracting an estimated legitimate night uses from the MNF.

MNF analysis could not be implemented under the current conditions of Sana'a water network because of the following reasons:

1. Supply in Sana'a water distribution system is intermittent and insufficient. Customers of Sana'a water utility use ground tank to store water for the times with no supply. These tanks will be being filled during the time of the experiment. Even though MNF could still be conducted when the customer tanks of the District Metered Area (DMA) are full, the distribution pattern of Sana'a water network is insufficient. Supply in Sana'a is dominated with short periods that are enough for filling the tanks in some zones, but not adequate to fill the tanks in some other zones (SWSLC, 2009b).
2. Zoning principle in general and the DMA concept in particular are yet neither have been adopted nor applied in Sana'a water network.
3. Applying DMA requires from 1000-3000 connections in the network to be separated and discrete. The DMA should be representative for the whole network in terms of population profile, leakage, and illegal connections. DMA should be hydraulically sound area with good records of pipes, fittings, and customer records. It is rather complicated under the current operational

conditions of the network to meet these conditions and implement DMA with appropriate water distribution pattern. Besides, the current knowledge about the network and its components (e.g. valves) in Sana'a water utility is not adequate to apply DMA

For these reasons, many trials to separate some zones failed. Water and Environment Center in Sana'a University (WEC, 2010) has tried to conduct MNF analysis in Sana'a water network. Sana'a water utility has arranged the technical team and the best hydraulically sound area with what thought to be an appropriate water distribution pattern. In spite of closing all the valves in the study area, water was still feeding some of customer tanks from unknown pipes. Due to the uncertainty of the network working nature, while customers' tanks were full at the time of the experiment in the areas that are close to the source of water, water had not yet been reaching the remote customers' tanks. Therefore, the trial of conducting MNF analysis carried out by WEC in 2010 has concluded that DMA needs minimum limit of hydraulic knowledge about the network to ensure completely separation the DMA. Sana'a water utility lacks adequate knowledge for such a purpose.

4.3.1.3 Component-Based Analysis

This method is not appropriate for assessing NRW in Sana'a water distribution system because of two reasons:

(1) This analysis is a data-based analysis; data availability and accuracy in Sana'a water utility is not adequately complete to conduct such analysis. There is a recent project applying the Data Center Maintenance Management Software (DCMMS) for recording the customers' complaints including the leakages. The program is adopted recently and has worked well in terms of reducing and managing the customer complaints. Nevertheless, yet the DCMMS in Sana'a water utility has only the total number of the

repaired leakages and has no data of the type of leakages that are reported in the system (whether it is in mains or in customer services). According to DCMMS data, Sana'a water utility estimates the amount of reported leakages based on the data of this program as 335 M^3 in the year 2009. This amount makes up 1.5% of system input volume and thus is too low for NRW level of 38% in Sana'a water distribution system.

(2) Thornton, et al. (2008) has recommended not using the component analysis, on its own to estimate the real losses because of significant level of uncertainty in much of the data used in the analysis. These uncertainties will increase and accumulate with the lack of data availability and accuracy in Sana'a water utility. As a result, using this method for NRW assessment would produces unrealistic results.

4.3.2 The Used Methodology

To sum up the above mentioned points, there are only three methods for NRW assessment. In the context of Sana'a water distribution system, none of these methods when used for NRW assessment would produce satisfactory results due to various reasons. Top down approach has the assumption of unauthorized consumption of 0.25% - 1% of the system input volume. This leads to underestimate the quantity of the apparent losses in Sana'a water network especially as this value is likely to have much higher percentage.

Bottom up approach requires hydraulic conditions that are not met by Sana'a water network's current conditions as concluded by the experience of Water and Environment Center (2010), and according to the zoning attempts made by the utility.

The third method, component based analysis, is a data-based method. NRW data in Sana'a water utility lacks accuracy and completeness. It is also recommended that the

component based approach should not be used on its own due to its high level of uncertainty.

Therefore, none of these methods could supply acceptable results for NRW assessment. In such a context, the suggested novel methodology, The Reverse Approach, has been applied to assess NRW in Sana'a water utility; SWSLC. Chapter 3 demonstrates the suggested methodology and presents the equations through which this methodology is implemented.

4.3.3 The Assessment Steps

The primary step is defining the volume of NRW by subtracting volumes of billed water from produced water. Then, determining the three components of NRW in the order as illustrated in Figure 4.1. First, unbilled authorized consumption was derived from Sana'a water utility's reports; next apparent losses were estimated using the suggested approach; and so Real losses were defined by subtracting the volumes of unbilled authorized consumption and apparent losses from NRW volume.

4.3.4 Determining Volume of NRW

NRW was set as the difference between adjusted produced water and adjusted billed water for the period of 2009 as shown in Figure 4.2.

First, the assessment period was defined. Then produced water (system input volume) was adjusted to production meters inaccuracies. Billed consumption (metered and unmetered) was obtained and computed. In the end, time lag between produced water and billed water was considered to give the adjusted volume of NRW.

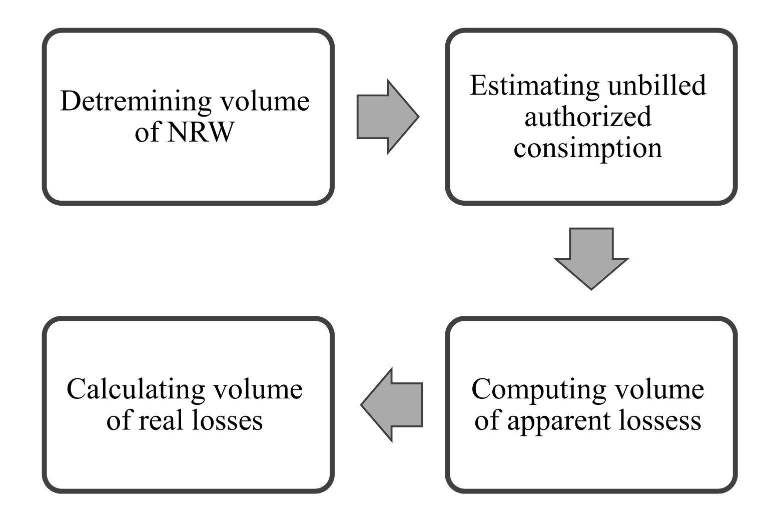


Figure.4.1: Process of NRW Assessment

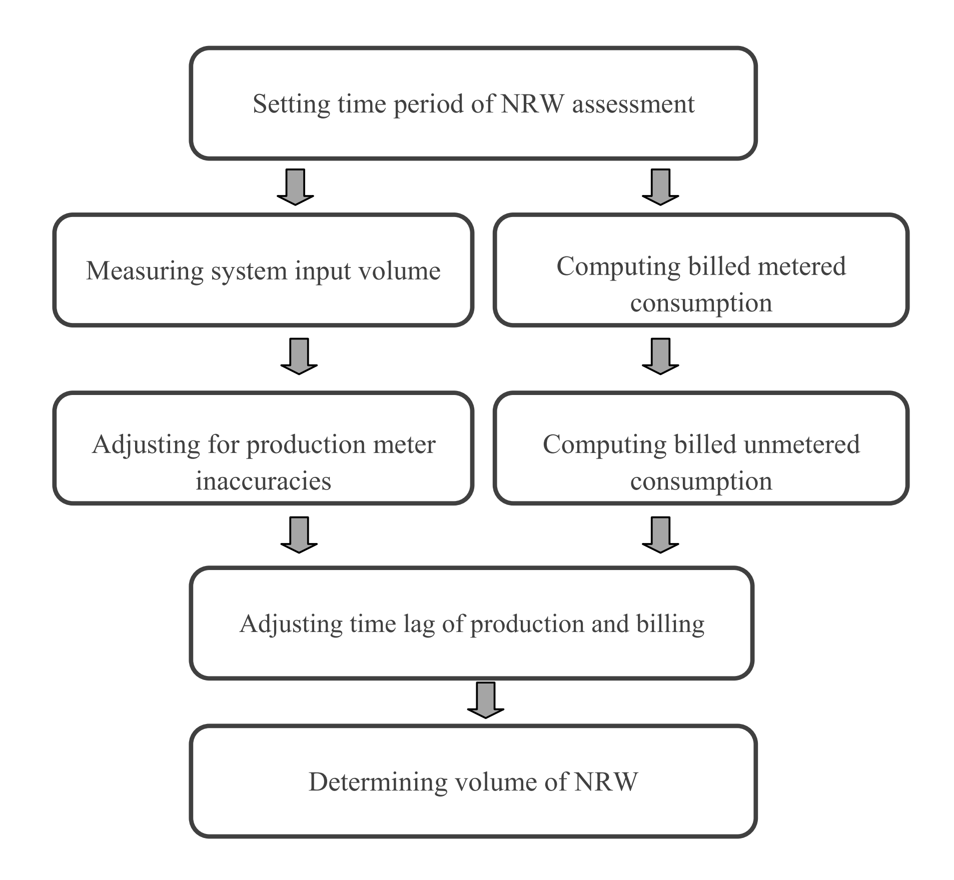


Figure.4.2: process of determining adjusted volume of NRW

Time period

For the purpose of assessing NRW in general, one year period is recommended by AWWA as it is long enough to include seasonal variations and reduces the effects of lag time in customer meter readings (AWWA, 2009). Hence, NRW in Sana'a water utility was assessed for one complete year; 2009.

System Input Volume Adjustment

The system input volume (produced water) was adjusted for production meter inaccuracies. Since it is not possible for the time frame of this study to conduct accuracy analysis and experiments for the production meters, the production meter inaccuracy was assumed at 7% under-registration based on the estimation of the production unit in Sana'a water utility. This estimation is justified by the following:

- There is no maintenance programmed for production meters by Sana'a water utility. The production meters are examined or maintained only once they are stopped or too low readings are obtained.
- Some meters are not installed according to their manuals that require minimum straight distance before water meter or specified sizes of pipe diameters.
- Water flow is of low level in the production pipes because of regression of wells' production as a result of water scarcity in the basin.

Billed Metered and Unmetered Consumption

Metered consumption and the estimated unmetered consumption of customers with flat rate policy were obtained from the billing records of Sana'a water utility. Then the billed water (metered and unmetered) was summed.

Lag Time Adjustment

For the reason that water produced in Sana'a water utility is billed after a month, the production data were taken for all the months of the year 2009 except January 2009. Instead, the billed consumption of January 2010 was counted to represent the consumption of December 2009. Other time lag adjustments were neglected.

After all, NRW volume was determined by subtracting the adjusted volume of billed water from the adjusted volume of produced water.

4.3.5 Estimating Unbilled Authorized Consumption

Unbilled authorized consumption has two types; metered and unmetered. The unbilled metered consumption in Sana'a water utility consists of the consumption of the staff in buildings belong to the utility as they are metered as well as the exemptions and wells guards' consumption.

The unbilled unmetered consumption in Sana'a water utility consists of water used for pipes washing, firefighting, special institutions, and consumption of some notable people. All these types are supplied by means of water tankers, and thus estimated by the number of the tankers per year for each type in every administrative zone.

The unbilled authorized consumption (metered and unmetered) was estimated by obtaining relevant data from the internal reports of the utility.

4.3.6 Calculating Volume of Apparent Losses

Adjusting the suggested approach for the case of Sana'a

Besides having an intermittent supply pattern, Sana'a water utility provides insufficient water for many zones in the city. This has led to emerging and expanding the industry of private water tankers as a supplement water supply for the city once there is water shortage at the customers' side.

The supplementary supply of Sana'a city enters the sewers and eventually reaches Sana'a wastewater treatment plant as illustrated in Figure 4.3 and Figure 4.4 For the purpose of calculating apparent losses by using the WWTP inflow measurements, volume of water supplementary supply that reaches WWTP should be considered. Therefore, Equation.3.5 of apparent losses determination in Chapter 3 was adjusted to Equation 4.1 in which supplementary supply is considered as follows:

Qa = Qww – Qbw – Quac + Qout + Qex – Qin - Qss…………………………………….....Eq.4.1

Where:

Qa: Apparent losses volume

Qww: Inflow of the wastewater treatment plant

Qbw: Billed water consumption.

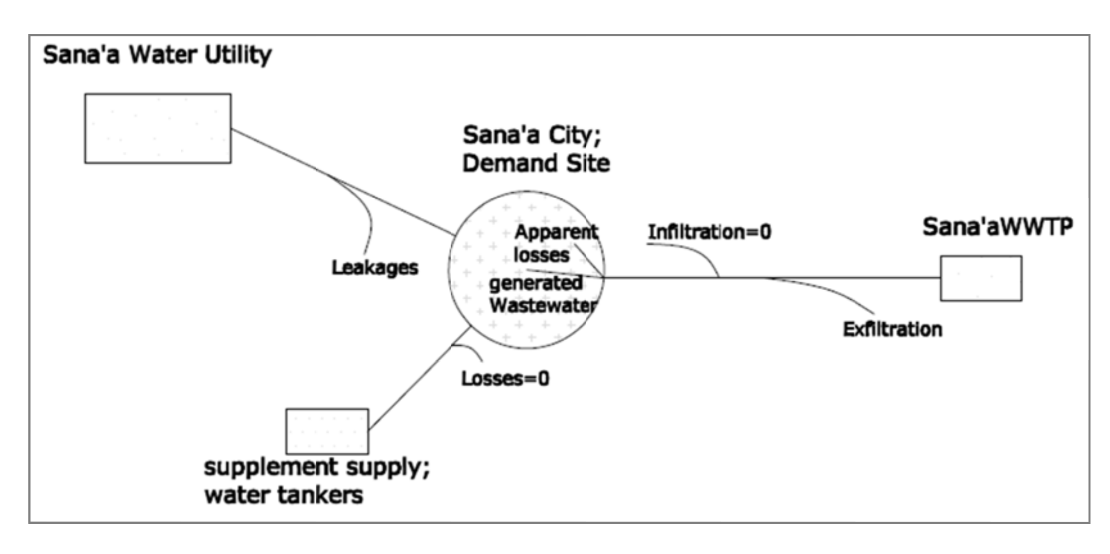
Quac: Unbilled authorized consumption;

Qout: Outdoor use consumption;

Qex: Exfiltration volume.

Qin: Infiltration volume

Qss: Volume of supplementary water supply that reaches the treatment plant and not considered in the billing records of the billed consumption.



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4.3.6. 1 Determining the components of Equation 4.1

In this part, methods of determining the components of Equation.4.1 will be presented in the same order of Equation 4.1.

1. ***Billed consumption and inflow measurements of Sana'a WWTP***

Billed consumption as well as inflow measurements of Sana'a wastewater treatment plant at its inlet were obtained with their respective number of wastewater connections.

In Sana'a water distribution system, there are connections with both services; water and wastewater. There are some other connections that are covered with water service and simultaneously not covered by wastewater services. To consider the billed water for those connections with water and wastewater services, the rate of billed consumption per one service connection was multiplied by number of "water and wastewater" connections to produce the corresponding billed consumption as shown in Equation 4.2 and Equation 4.3.

$Qconn = Qbcwc / Nw\ conn$……………………………………………………….……...Eq.4.2

$Qbcwwc = Qconn \cdot Nww\ conn$……………………………………..……………Eq.4.3

Where;

Qconn: Rate of billed consumption per each water connection

Qbcwc: Billed consumption for all water connections

Nw conn: Nr. of water connections

Qbcwwc: Billed consumption for connections that have water and wastewater service

Nww conn: Nr. connections that have water and wastewater service

Afterwards, the calculated volumes of apparent losses were modified for the whole water connections.

2. *Estimating the Outdoor Water Use in Sana'a City*

There are three methods for estimating outdoor use; summer winter method, minimum month method, and average winter month method (Chapter 3). All these methods depend on studying the seasonal variance of water consumption to deduce outdoor use consumption. In consequence, monthly consumption data are required to implement these methods.

There is no representative monthly consumption data for Sana'a city. Monthly consumption records in Sana'a water utility do not represent the real variance of seasonal consumption of consumers since supply by Sana'a water utility is insufficient. Most customers use all amounts of water they could get from Sana'a water utility to minimize the need for a more expensive supplementary supply via tankers. For this reason, two steps were made to estimate outdoor use consumption in Sana'a city:

(1) Estimating outdoor use for another city with similar influencing characteristics; and here the only city in Yemen with representative consumption data is Dhamar city.

Therefore, outdoor water use for Dhamar city was estimated to supply assumption for Sana'a city.

(2) Consulting local water experts in Sana'a city; water experts in Water and Environment Center in Sana'a University were consulted for estimating outdoor water use consumption in Sana'a city (WEC, 2010).

3. *Estimating Exfiltration from the Sewers*

The exfiltration from the sewers is estimated by deducting the wastewater generated at the demand site from the wastewater volume at the entrance of WWTP using Equation 3.6b. Despite the fact that there is no infiltration into the sewers in Sana'a wastewater network as the ground table is far enough from the sewers level, there might be marginal amount of water leakages that find its way to sewers and thus already implied in the equation.

$$Qex - Qinf = Np \cdot Qcap \cdot (1 - Qout\%) + Qind - Qww \qquad \text{Eq.3. 6b}$$

Where;

Qex: Exfiltration

Qinf: Infiltration

Np: Nr. of population served

Qcap: per capita water consumption

Qout%: outdoor use percentage from water consumption

Qind: Industrial wastewater discharge

Qww: WWTP inflow

Population served by wastewater service

There are no exact figures for how many people are served by wastewater service or water service. Sana'a water utility assumes the figure 6.9 people for each water connection or wastewater connection as there has not been any inventory in this regard. This figure is assumed after the statistical census in 2004 that has estimated the number of people for each family at 6.9 people (Central Statistical Organization, 2006). This

assumption implies that there is only one family served by each service connection which is not necessarily true. Therefore, figures of Sana'a water utility was not used for estimating exfiltration rate by Eq3.6b.

Instead, it was assumed that the number per each service connection is 13 people after AL-Washali, et al., (2006) who made a survey for 539 households in five different zones in the city. The survey has shown that around 48% of the surveyed connections serve one family, 33.7% for two families, 8.7% for three families, 4.6% for four families, 2.8% for six families, and 1.8% for eight families. Therefore, the average number of people served by each service connection is 13 people.

Hence, the population served by the service was calculated by multiplying this figure with the number of the service connection for the wastewater service.

Per capita consumption

Per capita consumption for Sana'a city as appears in the PIIS report of the Ministry of Water and Environment (MWE, 2008) is with an average of 61.4L/day for the year 2006 and 2007. This figure does not imply any losses as it is driven from the billing records and number of the consumers for these records in areas with sufficient supply.

Industrial discharge and WWTP inflow

The other data of the WWTP inflow measurement and the industrial consumption was obtained from Sana'a water utility. The industrial consumption is very low at Sana'a water utility and has types of industries that have no outdoor use such as central slaughterhouses; therefore, the discharge of the industrial activities was assumed to be similar to its consumption.

4. The volume of the supplementary Water Supply

Wells that contribute to the city supply and eventually their production were reflected in Sana'a WWTP inflows were first inventoried and then their production quantities were estimated. Figure 4.5 illustrates the process of estimating the supplementary water supply volume within the service areas of Sana'a water utility. GIS maps were generated to record the number of wells within the service area and then production of these wells were estimated based on a study conducted by National Water Resources Authority (NWRA, 2006b).

Inventory of wells' number

To have the right number of how many wells contributes to the city supply within service areas through water tankers, GIS maps were generated and then number of wells within the boundary of the service was defined by Sana'a water utility.

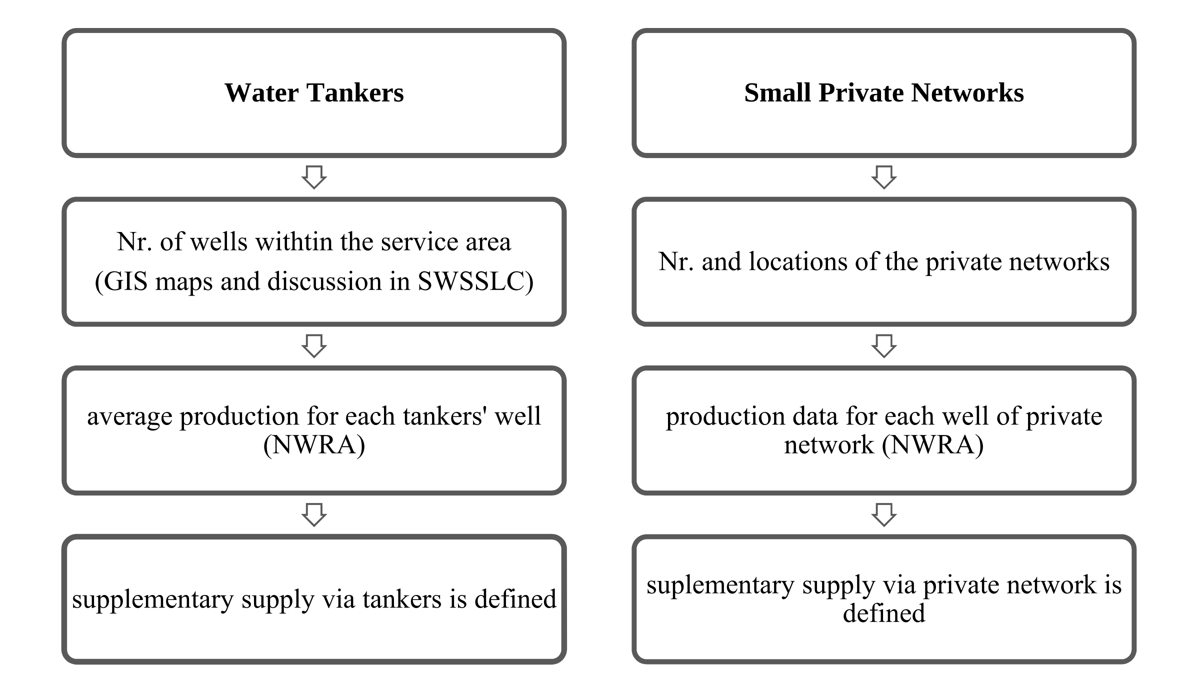


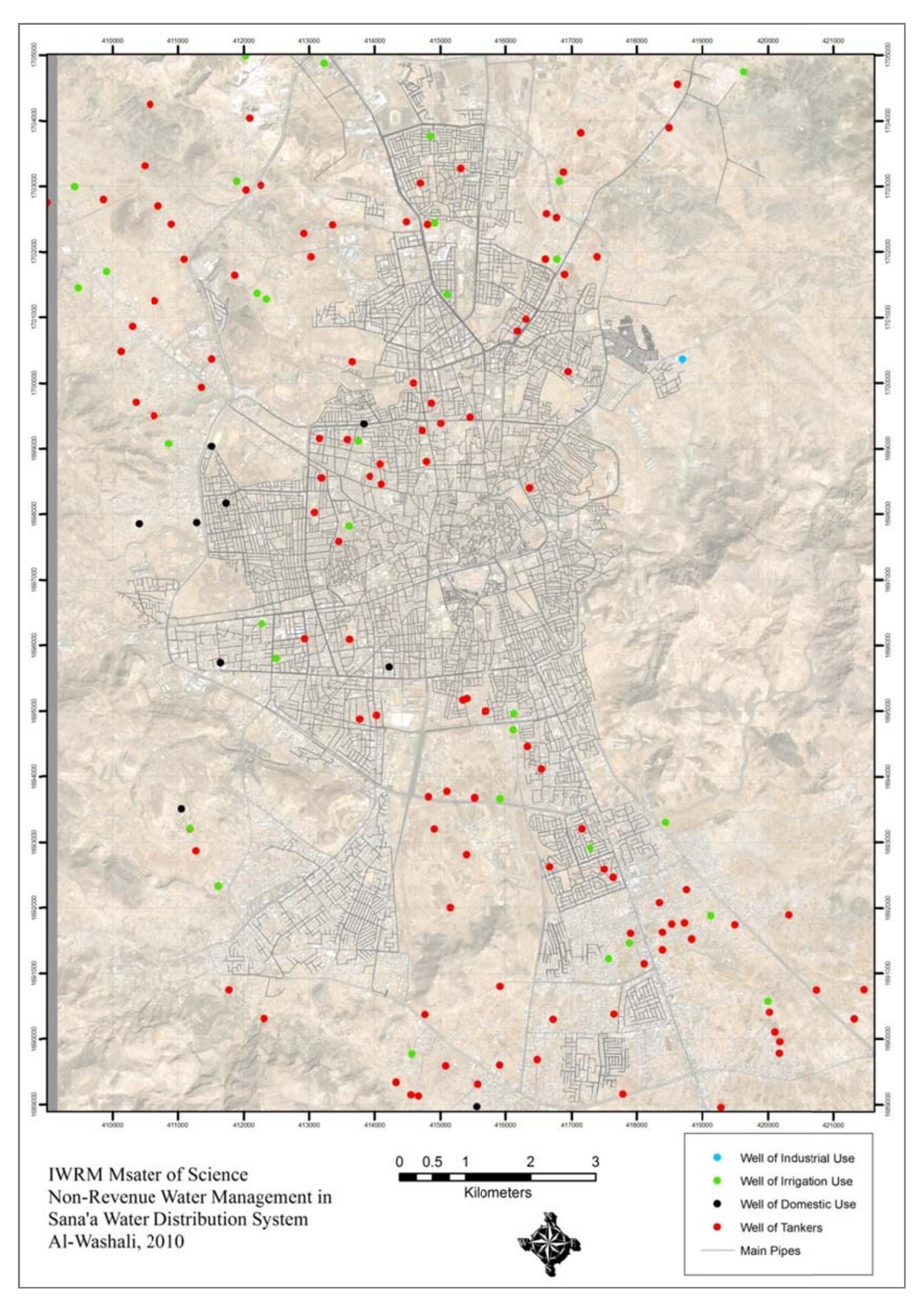
Figure.4.5: Proccess of estimating volume of suplementary water supply within service araes of Sana'a water utility

First, location data for all the wells in Sana'a were obtained from the database of NWRA (2010). Then, data of water and wastewater networks shape files were taken from the GIS units of Sana'a water utility. Both types of data as well as remote sensed image for Sana'a city were processed in the Arc GIS Packages to generate maps that contain the boundaries of water and wastewater network and the private wells used in the supplementary supply for the city as shown in Figure 4.6. Afterwards, the private wells used for filling water tankers within the places of the wastewater service were inventoried. Similarly, the locations of the few private wells that supply small private networks were obtained from the database of NWRA (2010) and reflected in Figure 4.6. Then, a discussion has been made in the wastewater projects department in Sana'a water utility to define the boundaries of the service in 2009. After all, the numbers of the wells that supplement the water supply in Sana'a city within the boundaries of the wastewater network were defined.

Estimation production quantity of supplementary supply

To determine the quantity of water that those wells produce annually, the production data and the tankers inventory were obtained from NWRA (2010, 2006b). The water tankers' inventory data shows the following

- Average number of the tankers filled by each well;
- Average number of times each tanker in the city is filled annually with consideration to the number of working days per year; and
- Average volume of the different shapes and types of tankers.


IWRM Msater of Science
Non-Revenue Water Management in
Sana'a Water Distribution System
Al-Washali, 2010
0 0.5 1 2 3
Kilometers
Well of Industrial Use
Well of Irrigation Use
Well of Domestic Use
Well of Tankers
Main Pipes

ntary

Based on these data the study provides the average production for each tanker's well in Sana'a in terms of the volume of the filled tankers per year. Part of this quantity is used for non-domestic uses and 87.3% is used for the drinking and domestic uses (NWRA, 2006b).

The other private wells that supply small networks have production data based on the average production flow and the working hours per year, and thus is also obtained from the database of NWRA.

For the five private networks that are located within service area, it was assumed that there are no losses and leakages in these networks as NRW level in these small networks is very low and the leakages are with negligible quantities (Al-Hamdi, 2000).

Henceforth, the additional water that reaches the WWTP besides that produced by SWSLC was calculated for the subject service connections, and thus, Equation 4.1 for the suggested approach is computed, and the volume of the apparent losses component was determined.

4.3.7 Calculating the real losses

As the apparent losses are defined and the unbilled authorized consumption is estimated, then real losses could be calculated straightforward from the following formula:

Real Losses = NRW- Apparent Losses - Unbilled authorized consumption

4.3.8 Using NRW software

There are three main reasons for integrating NRW software in the process of NRW assessment in Sana'a water utility: (1) To visualize the results in form of the standard NRW water balance; (2) To avoid the calculating errors during the assessment process; and (3) To derive the cost of NRW components.

There are two common free computer applications for NRW assessment: one sponsored by the World Bank Institute *(Free Water Balance Software V.3)* and the other created by American Water Work Association *(AWWA WLCC Free Water Audit Software V.4.2.)* Figure 4.7 and Figure 4.8 show both applications' interfaces.

AWWA WLCC Free Water Audit Software does not take into account explicitly the characteristics of the intermittent supply. Therefore, the value produced by this software is misleading for systems with intermittent supply unless the period analysis is adjusted at the beginning of the analysis. In contrast, *Free Water Balance Software V.3* takes intermittent supply pattern into account and further, has more options for results presentation.

The *Free Water Balance Software V.3. (WB-EasyCalcV.3)* was used because Sana'a water supply is intermittent. Results were eventually presented in a form of the standard water balance for NRW assessment. After all, costs of NRW were also computed by this software after entering the average domestic tariff and water production cost per each cubic meter.

AWWA Water Loss Control Committee (WLCC) Free Water Audit Software v4.2

Copyright © 2010, American Water Works Association. All Rights Reserved. WAS v4.2

PURPOSE: This spreadsheet-based water audit tool is designed to help quantify and track water losses associated with water distribution systems and identify areas for improved efficiency and cost recovery. It provides a "top-down" summary water audit format, and is not meant to take the place of a full-scale, comprehensive water audit format.

USE: The spreadsheet contains several separate worksheets. Sheets can be accessed using the tabs towards the bottom of the screen, or by clicking the buttons on the left below. Descriptions of each sheet are also given below.

THE FOLLOWING KEY APPLIES THROUGHOUT:
Value can be entered by user
Value calculated based on input data
These cells contain recommended default values

Please begin by providing the following information, then proceed through each sheet in the workbook:

NAME OF CITY OR UTILITY: Sana'a Water Distribution Network   COUNTRY: Yemen

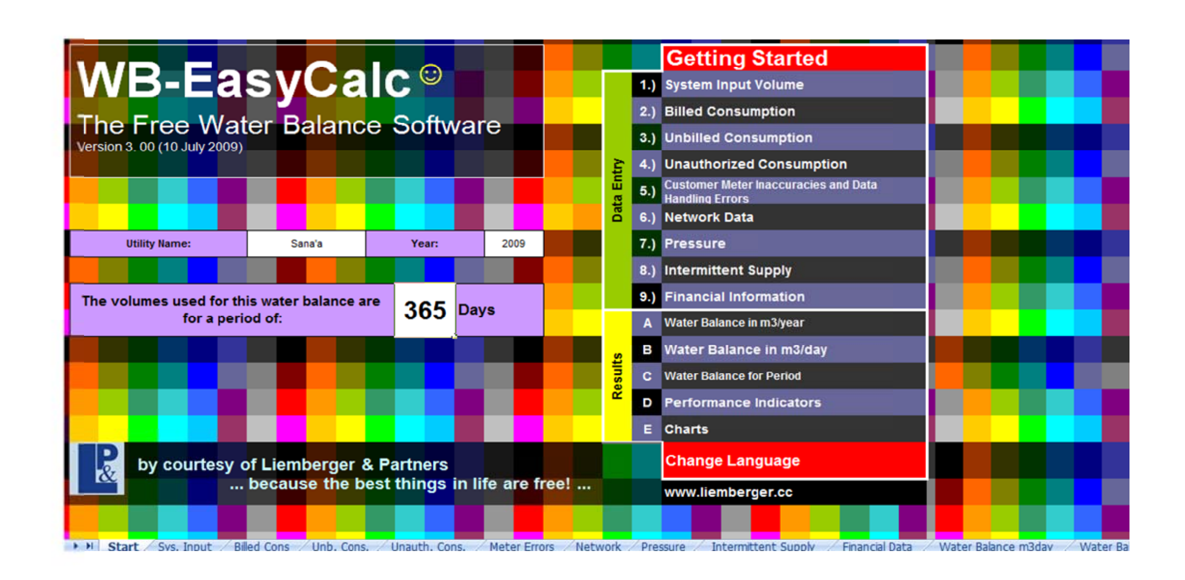
REPORTING YEAR: 2010   START DATE (MM/YYYY): 01/2008   END DATE (MM/YYYY): 31/12/2008

NAME OF CONTACT PERSON: Taha AL-Washali   E-MAIL: EngTaha3@gmail.com   TELEPHONE: Ext.

PLEASE SELECT PREFERRED REPORTING UNITS FOR WATER VOLUME Megalitres (thousand cubic metres)

Click to advance to sheet...   Click here: ? for help about units and conversions

Instructions	The current sheet
Reporting Worksheet	Enter the required data on this worksheet to calculate the water balance
Water Balance	The values entered in the Reporting Worksheet are used to populate the water balance
Grading Matrix	Depending on the confidence of audit inputs, a grading is assigned to the audit score



4.4. Results and Discussions

4.4.1. Volume of Non-Revenue Water

Non-revenue water in Sana'a water distribution system makes up 38.75% of system input volume as shown in Figure 4.9, and stands for 23665 M^3/day. Table.4.1 shows the volume of NRW, the volume of billed water, and the adjusted volume of produced water for Sana'a water distribution system with consideration to time lag adjustment in the year 2009. If no adjustment for the production meters inaccuracies were made, NRW would be 34.5% of system input volume. Therefore, 4.25% is losses that are important to be, but usually not, considered when determining the system input volume.

Table.4.1
Non-Revenue Water Volume in Sana'a Water Distribution System

Produced water (M^3/year) (A)		Total Billed Water (M^3/year) (B)		Non-Revenue Water (A-B)	
Measured	20,832,069	Metered	13,506,402	M^3/year	8,637,692
Adjusted for meter inaccuracies	1,458,245	Unmetered	146,220	M^3/day	23,665
Total	22,290,314	Total	13,652,622	% of system input volume	38.75

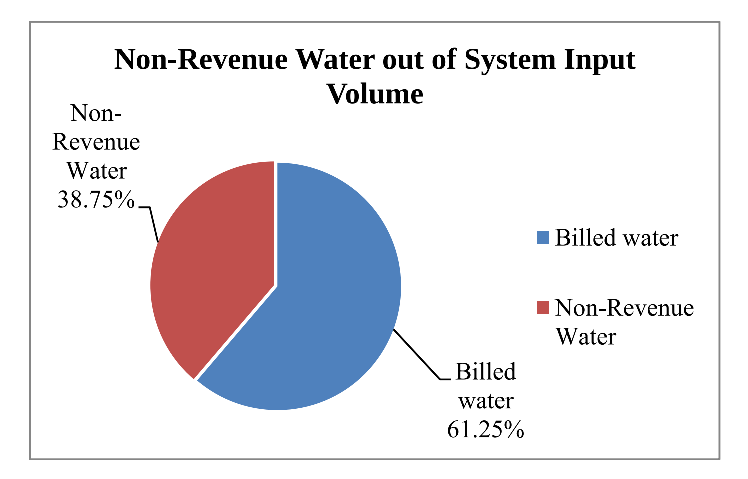


Figure.4.9: Non-Revenue Water out of system input volume

4.4.2. Unbilled Authorized Consumption

Table.4.2 shows the volumes of metered and unmetered unbilled authorized consumption for the year 2009. The total volume of unbilled authorized consumption is 114152 M^3/year which makes up 0.5% of system input volume. As shown in Table.4.2, 79% of unbilled authorized consumption is water delivered for special institutions and exemptions.

Table4.2
Unbilled Authorized Consumption

Metered (M^3/year)		Unmetered (M^3/year)		Total	
The utility and wells guards' consumption	17537	Pipes washing	3635	M^3/year	114152
		Firefighting	3550	M^3/day	313
Exemptions	26725	Special institutions and notable people	62705	% of system input volume	0.51
Total	44262	Total	69890		

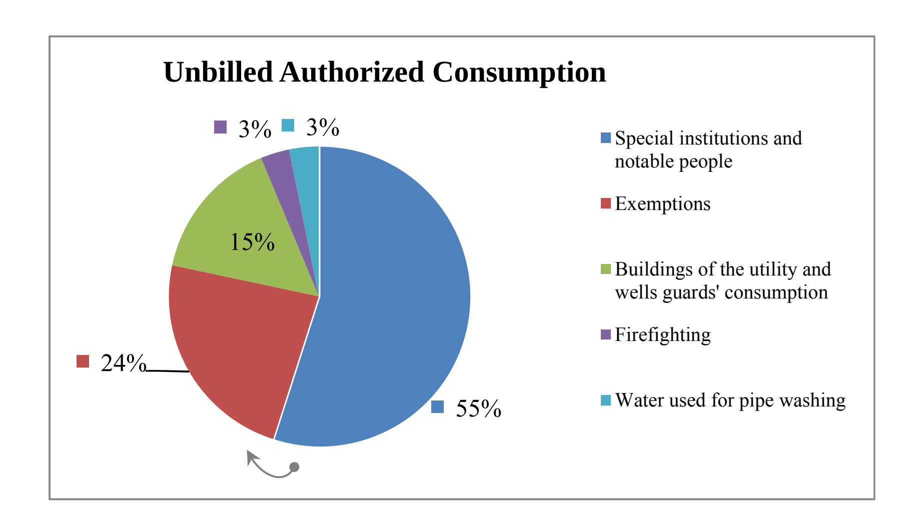


Figure.4.10: Unbilled authorized consumption in Sana'a water utility

4.4.3. Apparent Losses

Wastewater inflows and its respected billed consumption

Wastewater inflow as measured at the inlet of Sana'a WWTP is 19361500 M^3/year. The billed consumption for those connections of water and wastewater connections is 12760667 as shown in Table.4.3.

Table.4.3 Billed Water (M^3 per year)	
Total Billed water	13652622
Nr. of water connections	83374
Rate of billed water per connection	163.75
Nr. of WW connections	77927
billed water for WW connections	12760667

Outdoor water use consumption

As this dissertation seems to be the first study that attempts to estimate outdoor water use in Yemen, water experts of Water and Environment Center (WEC) were consulted for their expectations of outdoor use in Sana'a city. Experts of WEC (2010) expect outdoor water use in Sana'a city around 3%.

This low value is justified by the very limited areas of yards and irrigation land in the premises of the city. Jorgensen, et al. (2009) and Mitchell, et al. (1999) highlighted that there is a link between housing density and outdoor water use due to the size of the premises' gardens; Outdoor use generally increases with spacious blocks and decreases with high-density units in the city.

On the other hand, results of the three methods of outdoor water use estimation for Dhamar city would supply general trends of outdoor use in Yemen and allow realistic

assumption of outdoor use in Sana'a city. The average outdoor percentage of the three methods for Dhamar city is 6.45% of total water consumption.

For the purpose of this study it was assumed that outdoor water use in Sana'a should be around 4%. This assumption is supposed to be less than that the results of Dhamar city for two reasons: (1) house yards and irrigation areas of the premises in Dhamar are larger and more prevalent; and (2) water supply is continuous and completely sufficient in Dhamar since water service is covered 24/7.

Figure 4.11 presents the values of outdoor water use expected by local experts, outdoor water use of Dhamar, and the used assumption for Sana'a. Table.4.14 shows that the volume of outdoor water use for those served by wastewater services is 1720 M^3/day at the assumed outdoor water use of 4% of total water consumption.

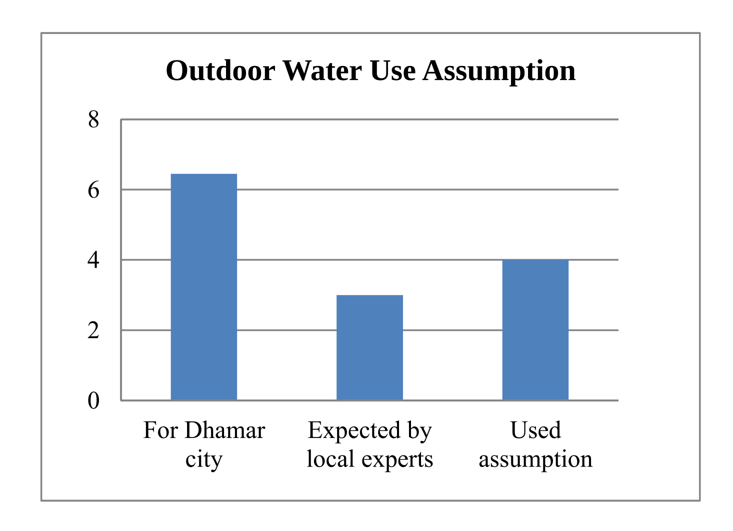


Figure.4.11: Outdoor Water Use Assumption for Sana'a city

Table.4.4
Volume of outdoor water use consumption at 4%

M^3 per year	627703
M^3 per day	1720

To analyze the impacts of outdoor water use on the accuracy of the results of NRW assessment in Sana'a water distribution system, apparent losses were manipulated with the outdoor percentage as shown in Figure 4.12. It is found that outdoor water use has no major impact on NRW assessment through the reveres approach; rather, it has a slight influence on the volume of apparent losses. As shown in Figure 4.12, each increase of outdoor water use by 1% causes apparent losses decreases by 0.28% of system input volume. Therefore, there is no significant influence of outdoor water use volume on volume of apparent losses. For Sana'a case, outdoor water use should lie between 3-5% of water consumption. If so, the precision of the results of apparent losses would be ± 0.28% of system input volume due to potential errors for estimating outdoor water use consumption.

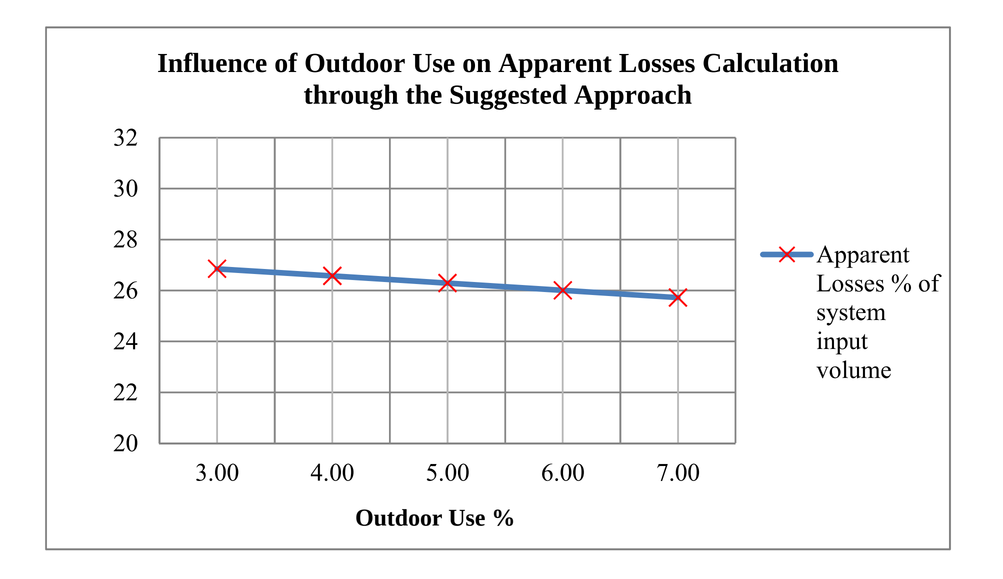


Figure.4.12: Apparent losses and outdoor water use manipulation

Exfiltration form sewers

As shown in Table.4.5, exfiltration volume was estimated at 3706 M^3/year using Equation 3.6b. In this equation, exfiltration is a function of per capita consumption and outdoor water use. The rest variables are of measured data that should have acceptable precision.

Table.4.5 Exfiltration	
M^3 per year	1352695
M^3 per day	3706
%of WWTP Inflow	7.7
%of Base Flow	7.1

To study the influence of exfiltration and its variables on NRW assessment by the suggested approach, per capita consumption was manipulated with the volume of apparent losses as shown in Figure 4.13. It was found that the precision of apparent losses is influenced by slightly change of per capita consumption. As shown in Figure 4.13, an increase of 1 L/day for per capita consumption shifts the apparent losses +1.63% of system input volume. Therefore, apparent losses and NRW assessment by the suggested approach is highly influenced by the precision of per capita consumption. For the case of Sana'a water distribution system, per capita consumption was obtained from reports of MWE as 61.4 L/day. However, SWSLC estimates the per capita consumption at 62 L/day. Other studies suggest per capita consumption at 59 L/day. Therefore, it is likely that per capita consumption lies between 59 and 63 L/day. If so, the apparent losses under the worst scenario could be the calculated figure by the

suggested approach ± 3.26 of the system input volume due to potential errors for estimating per capita consumption.

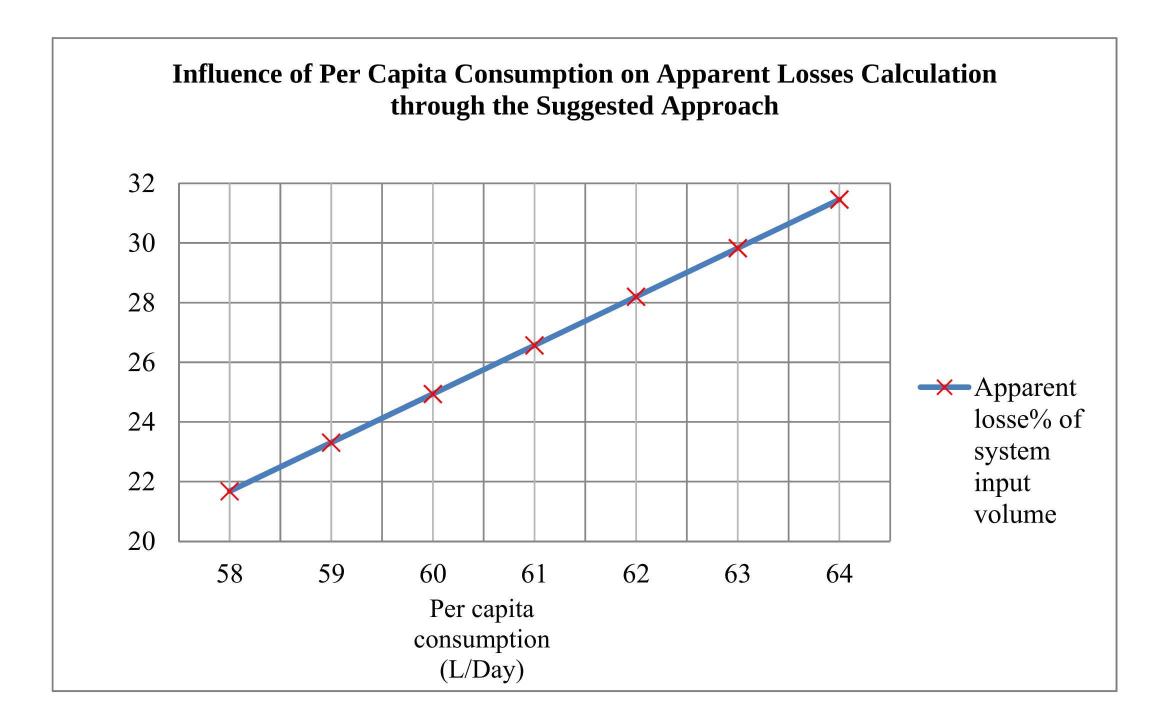


Figure.4.13: Per Capita Consumption and Apparent Losses Manipulation

Supplementary Supply

Table.4.6 shows the volume of supplementary supply for customers served by Sana'a water utility. The total volume of supplementary water supply is 8033 M^3/day of which 6453 M^3/day is provided via water tankers in 42 wells; and 1580 M^3/day is provided via five private networks within the coverage area of Sana'a water utility.

Unlike the private water networks that were defined precisely, defining exactly how many tankers' wells lie within the service area could be susceptible to human errors. In the studied case, although using GIS maps and discussions with relevant staff in Sana'a water utility, it is worth to investigate the influence of number of wells defined within the service area and the final result of apparent losses. Figure 4.14 shows that increasing

the number of wells by one well decreases the apparent losses by 0.26% of system input volume.

<table>
<tr><th colspan="6">Table.4.6
Supplementary Water Supply</th></tr>
<tr><td colspan="4">supplementary supply via private networks</td><td colspan="2">supplementary supply via filled tankers</td></tr>
<tr><td>Nr. of wells within the coverage area</td><td colspan="3">5.0</td><td>average water volume for each well (M^3/year)*</td><td>64233</td></tr>
<tr><td>average production flow for the wells (L/sec)</td><td colspan="3">8.65</td><td>% of domestic use</td><td>87.3</td></tr>
<tr><td rowspan="2">working hours</td><td colspan="2">dry seasons</td><td>2642</td><td rowspan="2">volume of domestic use for each well (M^3/year)</td><td rowspan="2">56076</td></tr>
<tr><td colspan="2">wet seasons</td><td>1062</td></tr>
<tr><td>total Supply (M^3/year)</td><td colspan="3">576713</td><td>Nr. of wells within the service coverage areas</td><td>42</td></tr>
<tr><td>total Supply (M^3/day)</td><td colspan="3">1580</td><td>total supply (M^3/year)</td><td>2355185</td></tr>
<tr><td colspan="4">* average water volume for each well is estimated based on 337.5 filled tankers per week and 3.65 average volume for the tanker (NWRA, 2006b)</td><td>total supply (M^3/day)</td><td>6453</td></tr>
<tr><td colspan="6">Total Supplementary Supply (M^3/year)</td></tr>
<tr><td colspan="6">2931898</td></tr>
<tr><td colspan="6">Total Supplementary Supply (M^3/day)</td></tr>
<tr><td colspan="6">8033</td></tr>
</table>

Therefore, no big influence do wells have on apparent losses determination. In the study case, worst scenario lies between 39-45 wells. Therefore, the apparent losses should be the estimated value by the suggested approach ± 0.78% of system input volume due to potential human errors when counting the number of wells within the service area.

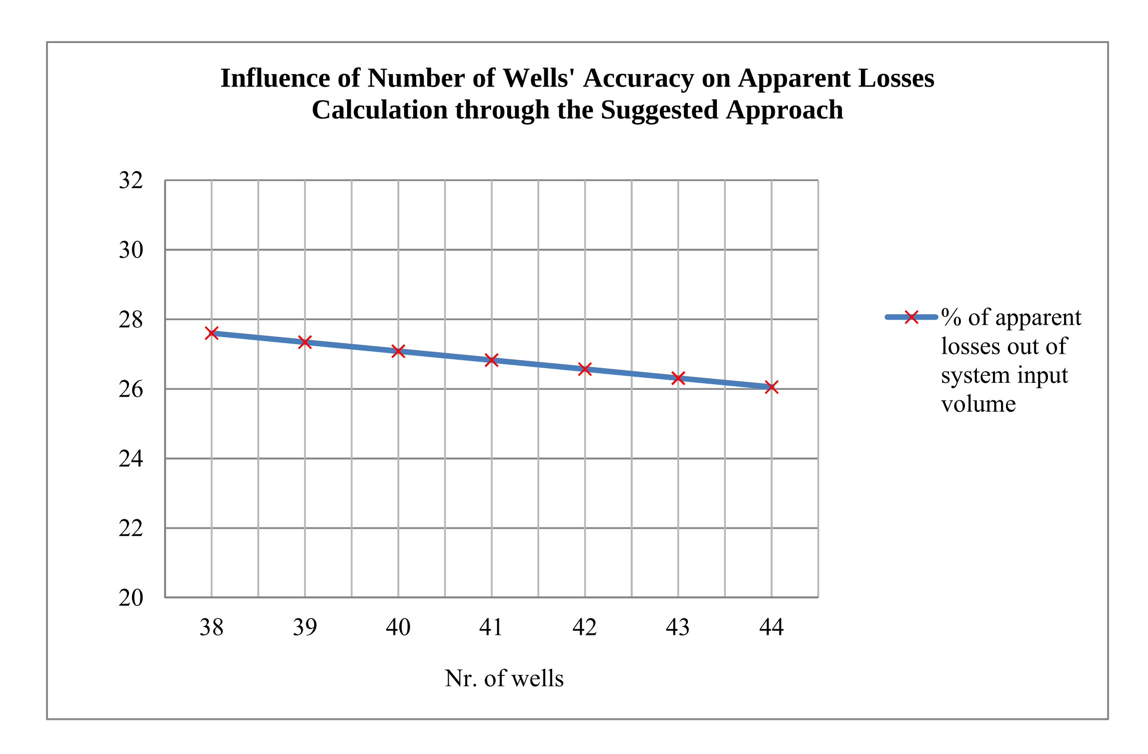


Figure.4.14: Number of Wells within the Service Area and Apparent Losses Manipulation

Aggregated precision

In light of the above discussion, the apparent losses value that is estimated by the suggested approach should have precision of ± 0.28%, ± 3.26%, and ± 0.78% for likely errors of estimating the outdoor water use, per capita consumption, supplementary water supply respectively. Therefore, the apparent losses under the worst scenario would be the value calculated by the suggested approach ± 4.32% of system input volume and ± 1.06% of system input volume when assuming that per capita consumption obtained from MWE is accurate.

Volume of Apparent Losses

Table.4.7 shows the volume of apparent losses in Sana'a water distribution system which is estimated using equation 4.1 at 16225 ± 2638 M^3/day. This precision level, even though significant, should be acceptable for two reasons: (1) there is no other methodology to estimate apparent losses in such a context of Sana'a water utility; (2)

initial water balance are usually have high level of uncertainty; then data improvement for the water balance should be a process that enhance the overall results of the water balance each time.

If per capita consumption that appears in the report of Ministry of Water and Environment (MWE, 2008) is precise, then the precision of the apparent losses would be 16225 ± 647 M^3/day which is within an acceptable range and stands for ± 1.06% of system input volume.

Table.4.7
Volume of Apparent Losses

M^3 per year	5922083
M^3 per day	16225

4.4.4. Volume of Real Losses

Table.4.8 shows the volume of real losses in Sana'a water distribution system. This volume makes up 5.13% of the safe yield of Sana'a basin as the safe yield of the basin is estimated at 50.7 MCM (JICA, 2006).

Table.4.8

Volume of Real Losses

M^3 per year	2601490
M^3 per day	7127

4.4.5. Non-Revenue Water Breakdown

Table.4.9 shows the three components of NRW as a percentage of system input volume. The dominant component of NRW is the apparent losses which make up 26.57% of system input volume and stand for 68.57% of NRW volume as shown in Figure 4.15. Real losses are only 30% of NRW volume in Sana'a water distribution system, and unbilled authorized consumption is of marginal volume with only 1.3% of NRW volume.

It is worth to mention that Sana'a water utility assumes 50% for apparent losses and 50% for real losses in its reports such as the production and distribution report (SWSLC, 2009b). Nevertheless, as will be presented in the next chapters, staff of Sana' water utility expect apparent losses to be around 60% and real losses around 40%. The outputs of NRW assessment of this study are close to what is expected by Sana'a water utility, but in an objective and scientific method.

Table.4.9
NRW out of System Input Volume

System Input Volume (M^3/day)	61069
Billed Water (%)	61.25
NRW (%)	38.75
Apparent Losses (%)	26.57
Real Losses (%)	11.67
Unbilled Authorized Consumption (%)	0.51

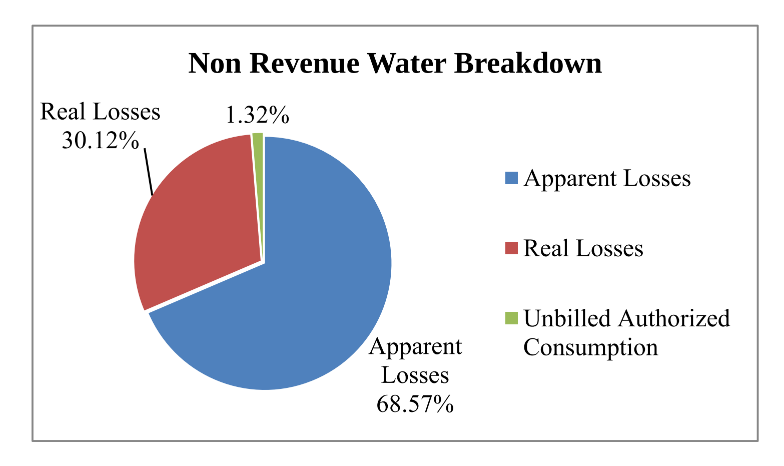


Figure.4.15: NRW breakdown in Sana'a Water utility

4.4.6 Water Balance for Sana'a Water Distribution System

Based on NRW assessment results through the suggested approach, Figure 4.16, Figure 4.17, and Figure 4.18 illustrate the final results of NRW assessment in a form of the standard best practice water balance as a percentage of system input volume, in M^3/year, and in M^3/day. *Easy-Calc. V3.0 Software* was used to produce the results of NRW assessment in the standard form recommended by AWWA and IWA.

Water Balance (%) of Sana'a Water Distribution System (2009)

<table>
<tr><td rowspan="6">System Input Volume
100 %</td><td rowspan="4">Authorised Consumption
61.76 %</td><td rowspan="2">Billed Authorised Consumption
61.25 %</td><td>Billed Metered Consumption
60.59 %</td><td rowspan="2">Revenue Water
61.25 %</td></tr>
<tr><td>Billed Unmetered Consumption
0.66 %</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption
0.51 %</td><td>Unbilled Metered Consumption
0.20 %</td><td rowspan="4">Non-Revenue Water
38.75 %</td></tr>
<tr><td>Unbilled Unmetered Consumption
0.31 %</td></tr>
<tr><td rowspan="2">Water Losses
38.24 %</td><td colspan="2">Apparent Losses
26.57 %</td></tr>
<tr><td colspan="2">Real Losses
11.67 %</td></tr>
</table>

Figure.4.16: Water Balance (%) of Sana'a Water Distribution System - 2009

Water Balance (M3/year) of Sana'a Water Distribution System (2009)

System Input Volume 22290314 M3/year	Authorised Consumption 13766774 M3/year	Billed Authorised Consumption 13652622 M3/year	Billed Metered Consumption 13506402 M3/year	Revenue Water 13652622 M3/year
			Billed Unmetered Consumption 146220 M3/year	
		Unbilled Authorised Consumption 114152 M3/year	Unbilled Metered Consumption 44262 M3/year	Non-Revenue Water 8637692 M3/year
			Unbilled Unmetered Consumption 69890 M3/year	
	Water Losses 8523573 M3/year	Apparent Losses 5922083 M3/year		
		Real Losses 2601490 M3/year		

Figure.4.17: Water Balance (M3/Year) of Sana'a Water Distribution System - 2009

Water Balance (M3/day) of Sana'a Water Distribution System (2009)

System Input Volume 61069 M3/day	Authorised Consumption 37717 M3/day	Billed Authorised Consumption 37404 M3/day	Billed Metered Consumption 37004 M3/day	Revenue Water 37404 M3/day
			Billed Unmetered Consumption 401 M3/day	
		Unbilled Authorised Consumption 313 M3/day	Unbilled Metered Consumption 121 M3/day	Non-Revenue Water 23665 M3/day
			Unbilled Unmetered Consumption 191 M3/day	
	Water Losses 23352 M3/day	Apparent Losses 16225 M3/day		
		Real Losses 7127 M3/day		

Figure.4.18: Water Balance (M3/day) of Sana'a Water Distribution System - 2009

4.4.7. Cost of Non Revenue Water

The annual revenues of Sana'a water utility is 1687 million YR in 2009 ($ 7.88 million) (SWSLC, 2009). With total billed water in 2009 at 13652622 M^3, the rate of revenues per one cubic meter is 123, 59 YR ($0.577 as in December 2010). Besides, the production cost per each cubic meter is 69.44 YR ($0.324) (SWSLC, 2010c).

Based on these data the *Easy-Calc. V3.0 Software* drew the costs of NRW components providing the average revenue for valuing the apparent losses and average production cost for valuing the real losses. Figure 4.19 and Figure 4.20 show the cost of NRW in YR and USD. NRW in 2009 cost Sana'a water utility 920.6 million YR ($4.3 million) of which 79% are apparent losses. Real losses and unbilled authorized consumption cost Sana'a water utility 20% and 1% respectively.

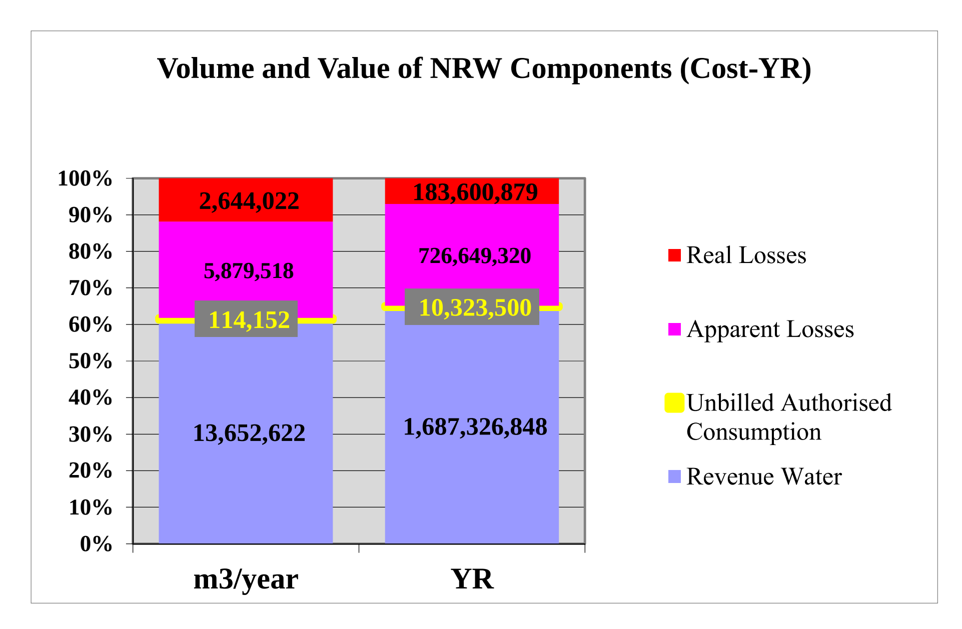


Figure.4.19: Cost (Yemeni Rial) of NRW in Sana'a Water Utility -2009

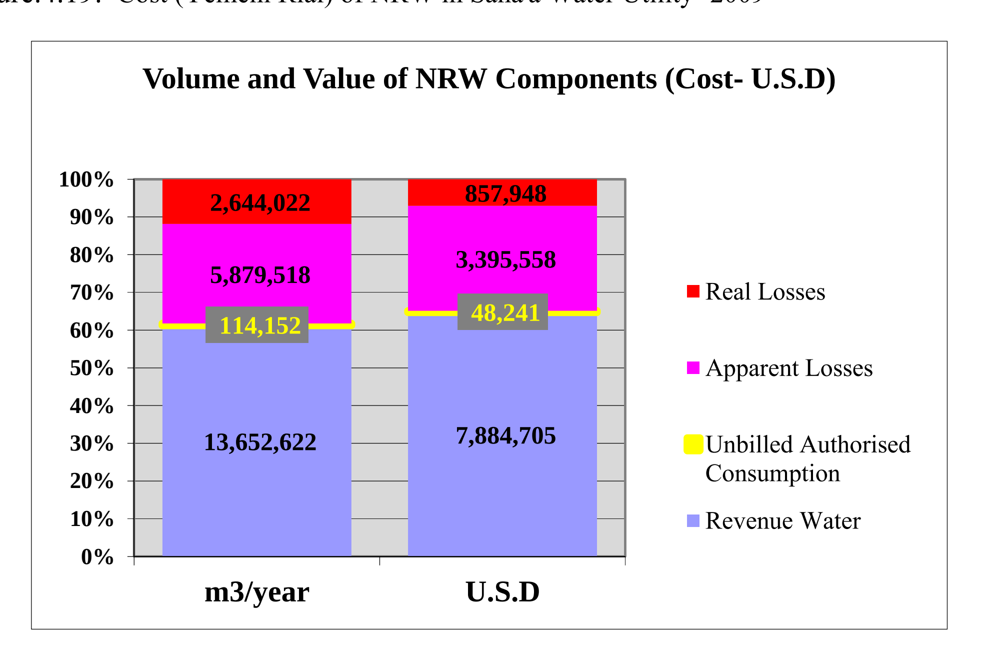


Figure.4.19: Cost (U.S.D) of NRW in Sana'a Water Utility -2009

4.5. Conclusion

4.5.1. NRW Assessment in Sana'a Water Distribution System

It is worth to mention that no step can be made towards designing NRW management strategy without the assessment phase. Although it seems to be complicated and data consuming process, efficient NRW management needs prioritizing of NRW components as the first step for its management.

This study is the first study attempted to breakdown NRW components for Sana'a water distribution system and the first in the country as well. It suggested an approach through which water utilities in Yemen can breakdown NRW and draw their water balances. Sana'a water distribution system was a pilot case study for applying this approach. Main conclusions made by NRW assessment for Sana'a water utility are as follows:

- When considering production meter inaccuracies, Non-Revenue Water in Sana'a water distribution system in 2009 makes up 38.75% of system input volume of which 26.57% is apparent losses; 11.67% is real losses; and 0.51% is unbilled authorized consumption.
- The precision of the apparent losses and consequently real losses is ± 1.06% for the assessment through this approach assuming that data obtained from Ministry of Water and Environment and Sana'a water utility are accurate.
- Apparent losses are the dominant component of NRW in Sana'a water distribution system and stands for 68.57% of NRW volume. Conversely, real losses and unbilled authorized consumption make up 30.12% and 1.32% of NRW volume respectively.
- The cost of NRW is high. NRW in 2009 cost Sana'a water utility 920.6 million YR ($4.3 million) of which 79% are apparent losses, 20% are real losses, and 1% unbilled authorized consumption.

- NRW assessment show that apparent losses volume should be prioritized for NRW management since it is dominant and its management is cost-effective.

4.5.2. The Suggested Methodology

- NRW assessment in water utilities with expected high unauthorized consumption is difficult. Top down approach is not recommended as it underestimates unauthorized consumption unless objective estimations for unauthorized consumption are available. On the other hand, the only recommended other method of NRW assessment is bottom up approach which estimates NRW through conducting DMAs and zoning principle in their water distribution systems. This, in turn is advanced phase of NRW management as it is part of assets and infrastructure management which requires high technical and financial resources.
- The suggested approach is an added value in the literature of NRW management. It provides an alternative methodology of NRW assessment and breakdown for water utilities in countries where unauthorized consumption is expected to be high such as developing countries. In such a case, this approach serves as an alternative for top down approach that developed by AWWA and IWA. The suggested approach uses usually available data of WWTP inflows, per capita consumption, number of people served and billing records of water utilities. All these data should be available in any water utility.
- It is found in this study that determining the volume of apparent losses is sensitive to precision of per capita consumption when exfiltration volume is estimated through Eq.3.6b. Therefore, for the purpose of using Eq3.6b for estimating the volume of exfiltration, per capita consumption should be estimated precisely or other ways of estimating exfiltration rate should be used.

- It is found in this study that accuracy of estimating outdoor water use consumption has no significant influence on NRW assessment through the suggested approach. This was due to the low level of outdoor water use consumption in Sana'a city. Where there is high level of outdoor water use consumption, further analysis should be conducted to evaluate the impact of outdoor water use consumption' accuracy on NRW assessment through this approach.

Chapter 5

Current NRW Management in Sana'a Water Utility

5.1 Research Questions

How does Sana'a water utility determine NRW, apparent losses, real losses, and unbilled authorized consumption of its water distribution system?

What are NRW performance indicators and reduction policies adopted by Sana'a water utility?

5.2 Research Method

To answer the objective questions of this part, related data and reports were collected from all the relative units and departments in Sana'a water utility; extensive review of relevant data and reports has been conducted, field visits to the points of data sources have been made, and exhaustive interviews (32 interviews; pre-interviews, structured and semi-structured interviews) throughout the different departments in the utility headquarter as well as the administrative zones have been carried out (Appendix.2). These tools were also used for the last objective of the research.

5.2.1 Data Collection

Non-Revenue Water data were collected from the relevant units. The production data was collected from the production unit; the annual records of leakages and repaired leakages were acquired from the compliance and maintenance unit; water distribution pattern was taken from the distribution unit; network data was gathered from the GIS unit; and water tariffs, billing records, number of customers, active and inactive accounts, metered and non-metered customers, and inactive meters were gotten from the commercial department. Besides, the annual performance and progress reports of SWSLC were obtained from the statistical unit. Furthermore, NRW performance indicators were collected from the Performance Indicators Information System (PIIS) reports from the Ministry of Water and Environment (MWE, 2008). In addition, several field visits to the reservoirs, production pumps, and production unit have been made to consider the flow of NRW data on one hand and to assess the accuracy of the subject data on the other hand.

To have a closer look at the procedures of NRW calculation, the internal reports of the technical departments were tracked, obtained, and analyzed and then, further discussed in the interview phase.

Nonetheless, it is worth to mention that data acquisition in Sana'a water utility is a hard task. The Information Technology department is still recent, young and lacks a lot of data. The secretarial work of the technical and commercial units and departments are of poor information management. The data are scattered in the specialists' laptops or PC's. Those, in turn, are either in the field or not often in their offices for various reasons. Once the needed specialists are found, they need a complex routine of approvals for data access. When the data are obtained, some data are missing, and the rest are of

questionable accuracy. However, for the purpose of this research, where no data analysis is required, it is assumed that obtained data are accurate.

5.2.2 Field Visits

Due to the importance of the data processing and accuracy of the production input volume in NRW calculation, field visits were conducted to the master meters, main pumping station, and main reservoir to have a closer look at how the production data flow through the production unit to the technical department. The way through which production data were read, recorded, and reported was tracked in order to conclude what the technical department's figures really measure.

Besides, visits to the fifth administrative zone were carried out to investigate the estimates methods and the terms used in NRW internal reports that are usually sent up to the utility headquarters.

In addition, a recent project of NRW reduction through pressure management, implemented by VAG Consultant was investigated to consider the project status and to derive lessons learnt.

5.2.3 Interviews

Since NRW issue interlinks with almost all the units and departments of the utility, thirty two pre-interview, semi-structured, and structured interviews as well as re-interviews were carried out for several units based on various sub-purposes.

Ministry of Water and Environment was targeted to tackle the legal and political dimension of NRW management. German Technical Cooperation was approached to consider the international cooperation aspects in NRW reduction through the ongoing

operation and maintenance projects with NRW reduction activities on one hand and to highlights the potential contribution of the research in the project on the other hand.

The purpose of the pre-interviews' questions was to realize the structure and dimensions of NRW management in the utility, the hierarchy of the utility, the Ministry of Water and Environment role, and the research authorization matter. In contrast, re-interviews were implemented to check and insure the critical information extracted from the interviews.

The interviews techniques were conducted in accordance with the interview guidelines proposed by Steinar (2007). In his guidelines, Steinar has highlighted the importance of recording and transcription the interviews. Nevertheless, recording the interviews were not applied in this research since it affects the "inter"- "view" process in the research's case. In Sana'a water utility, it is rather difficult for the employees to give direct statements when demonstrating their perspectives for issues related to their professions. This would be more difficult and thus rejected when it is a recorded interview as concluded from the pre-interviews phase. Instead, questions were prepared in advance, and notes were taken immediately in the same language of the interviewee. Then the interview notes were analyzed, and re-interviews were made when critical points have to be rechecked.

Other aspects of the interviews techniques were considered during the implementation phase. Main points of these techniques are: asking understandable and clear questions; listening carefully to the answers; paying attention to the voice as indication of the topic's importance and sensitivity; following up the important statements with second question; noticing the effects of the questioning style on the answers; translating the oral language into written language; considering ethical transgressions; and avoiding filling the interview with small talk (Steinar, 2007).

The interviews were made during the timeframe from 6th October to 7th of November 2010 (Appendix 2) during the work time in the offices of Sana'a water utility; SWSLC. The durations of the interview ranges from 10 to 150 minutes depending on the topic, purpose, and the interaction process of the interview; however, the average duration was about 25 minutes. Eventually, the final conclusions of the interviews were deduced and therefore, the purposes of the interviews were achieved.

In conclusion, the interviews were conducted in accordance with the interview guidelines proposed by Steinar (2007). To ensure the completeness of the interviews, exhaustive interviews were conducted. To increase the accuracy and avoid biases of the interviews, some re-interviews were made, and certain questions were re-asked in other interviews. To fulfill the confidentially ethics, the interviewees were informed about the purpose of the study, voluntary participation, and permissions have been taken. Afterwards, the data were synthesized and organized, information was presented, and conclusions were deduced.

5.3. Results and Discussion

This section summaries the main aspect of NRW current management in Sana'a water utility. However, a detailed presentation for the results of this chapter is provided in Appendix.3.

5.3.1. NRW Assessment

Sana'a water utility underestimates the amount of NRW in its water distribution system through two main actions: (1) The utility discounts significant amount of losses that the utility knows its causes such as estimated amount of repaired leakages and unbilled

authorized consumption; (2) No adjustment is made for system input volume although the utility estimates production meters inaccuracies around 7% under-registration.

An example for that is volume of NRW for the year 2009 which is 38.75%. The utility estimated it at 29%.

5.3.2. NRW Breakdown and Performance Indicators

There is no rule or methodology of NRW break down in Sana'a water utility. The utility does not assess the components of NRW. While some of the utility reports assume 50% of the losses to be apparent and the other 50% to be real, the dominant expectation of the losses among the staff of the utility is around 60% for the apparent losses and 40% for the real losses.

Regarding the performance indicators, the only used NRW performance indicator is volume of NRW expressed in % of system input volume.

5.3.2. Real losses

The main trials have been made by Sana'a water utility to reduce real losses are: zoning; installing Data Center Maintenance and Management Software; activities of network rehabilitation; and pressure management.

- Many trials have been made to reduce leakages through zoning, but were encountered with incompleteness of knowledge about locations of valves. They also were faced by multi-feeding source of water for each zone or area. So far, no trial has succeeded.
- Sana'a water utility has installed Data Center Maintenance and Management Software (DCMMS). It is a system for customer complaints and reported leakages' maintenance. The system has a "hot line" through which customers' complaints are recorded systematically and the time period of repairing the

leakages is then counted and documented with all data involved. The system started to work recently (2009) and the average recorded repairing time is 123.7 hours for 2354 leakages in the year 2009.

The existence of DCMMS system contributed for real losses reduction through accelerating repairing time of leakages. However, there is still high potential for enhancing the reactive management of leakage through this system; by achieving shorter repairing time as its average current repairing time is 123.7 hours per leak.

- Another trial is a recent project for pressure management for hilly area in Nokom in the first zone. The project aimed at reducing pressure by installing Pressure Reducers Valves (PRV); however, the project has failed because of intermittent supply for both water and electricity. Even though the project is still recent (2008-2009), it is already stopped.

5.3.2. Apparent losses

In general, Sana'a water utility manages apparent losses through policies that are not component-based. It neither has NRW strategy nor does it have NRW components' prioritizing policy. While its focus and effort is in reducing meter readers' errors and readers corrupting practices, there are no enough measures for illegal use reduction.

5.3.2.1. Reduction activities

- Training for meter readers has been recently intensified within the operation and maintenance program sponsored by GTZ trying to reduce meter reading errors and associated corrupting practices.

- Sana'a water utility conducts several, but not enough, investigation campaigns for stopped meters or customers with too low consumption. Then estimated

consumptions are determined based on historical data, and bills are distributed with the estimated consumption.

- There were a lot of exemptions from paying water bills for the employees of the utility and some customers. The policy now is replaced by providing incentives in term of money rather than exemption of unlimited volume of water.
- Sana'a water utility has suited many customers for illegal water use. However, the utility disregard this policy for the following reasons:
    - The lack of clear laws and legislations dealing with illegal water use
    - Lack of court ruling enforcement

- Sana'a water utility intends to utilize religious position for limiting illegal water use and has unofficial fatwa from Mofte of the Republic of Yemen denying using illegal water for public use (particularly mosques). However, yet, no official fatwa has been obtained by Sana'a water utility nor a planned commercial advertisement has been implemented.

5.3.2.2. Related Illegal water use policy

Analyzing the sales' records, Sana'a water utility found that more than 50% of its customers consume 1-10 M^3 per month. It found that 33% of the customers lie in the first tariff block and consume 1-5 M^3 per month. The utility doubts that this amount is enough for half of the customers and assumes that this indicates the high level of illegal water use. To treat the low level of revenues caused by illegal water use, the utility decided that 10 M^3 per month is the minimum limit of consumption.

This reactive policy is neither water conservative nor pro poor policy. The tariff blocks were designed by Ministry of Water and Environment (MWE) based on estimation consumption of poor in Sana'a city around 5 M^3 per month and therefore, the first block of tariff structure was designed from 1-5 M^3. Thus, the new policy contradicts the tariff structure designed by MWE. Further, it is likely that those customers who consume less than 10 M^3 per month would increase their consumption since they already pay the price of "water" and "wastewater" for the10 M^3 every month.

5.3.3. Other Critical Points

Three other critical points should be mentioned in this section with regards to current NRW-relevant policies in Sana'a water utility: employees' loyalty, the utility – customer relation, and number of disconnected customers. All of these points should contribute to high level of illegal water use and apparent losses.

Employees Loyalty and Commitment

Out of 40 tampered meters a week that reach meters workshop in the utility headquarters, 30% of these meters are tampered professionally by technicians of Sana'a water utility as estimated by the workshop experts. This point indicates the low level of loyalty of low level employees in Sana'a water utility. This in turn is due to low level of incentives or job stability of the segments of low level employees.

Another point that could be mentioned here is the contradiction of how influential meter readers might be and how good they indeed are. This contradiction could be concluded from the following two statements for the commercial manager and the manager of the fifth administrative zone respectively.

"…those who fail in fulfilling their duties or punished by their mangers are usually sent to work as meter readers…"

"…a meter reader is the center of the utility performance, once he is good; the utility works as the clock…"

The Utility – Customers Relation

There is a weak utility-customer relation associated with low level of customer confidence on Sana'a water utility. Significant decline of customer confidence level has been recognized since the new dry water meters that "could" record air in the network when air goes through the meter have been installed at the same time of raising water tariff. Carrying out these two procedures at the same time has weakened the relation of customers with the utility and affected the customers' confidence level.

Disconnected Customers

Among 18445 customers that were disconnected in 2009 because they didn't pay the bills, only 2705 are reconnected in the same year. These figures are also close to those of year 2008, 2007, 2006, and 2005 according to SWSLC annual reports. Accordingly, about 15740 customers are still disconnected in spite of the fact that water price from tankers are much higher than that provided by Sana'a water utility ($1.7 and $0.65 per M^3 respectively).

5.4. Conclusions

- There is no assessment and consequently no management prioritizing for NRW components in Sana'a water utility. As a result, NRW management is inefficient. It treats the obvious NRW elements without consideration to its contribution to the volume of NRW. An example, the utility measures focus on reducing meter readers' errors more than illegal water use.

- Sana'a water utility underestimates the volume of NRW significantly by discounting leakages and unbilled authorized consumption, and neglecting production meters inaccuracies.
- Sana'a water utility has made many attempts to reduce real losses; pressure management, zoning, and installing DCMMS system. All encountered with many difficulties and thus did not progress apart from DCMMS system. The system enhanced the reactive leakage management in Sana'a water distribution system. However, there is a lot of potential to further improve it by achieving shorter repairing time for the reported leakages.
- Illegal water use is significant and underlying in Sana'a water distribution system. The following two indicators points toward it:
    - When Sana'a water utility analyzed the sales' records, it found that more than 50% of its customers consume 1-10 M^3 per month and 33% of the customers lie in the first tariff block consuming 1-5 M^3 per month. The utility doubts that less than 5 M^3 per month is enough for 33% of its customers and assumed that many of these customers use bypass illegal connections.
    - Among 18445 customers that were disconnected in 2009 because they didn't pay the bills, only 2705 are reconnected and 15740 customers are still disconnected in spite of the fact that water price from tankers are significantly higher than that provided by Sana'a water utility ($1.7 and $0.65 per M^3 respectively).
- Two main factors contribute to high level of illegal water use;
    - Poor customer-utility relation: The utility had not raised tariff or substitute water meters for long time, and at once, it substituted water meters with new

ones that could record air; and simultaneously raised the tariff. The customer who used to pay the bill at certain range of price for years suddenly found unexpected increase of his bill. Customers then assumed that the new meters is the reason for the bill increase and this increase is just air recorded by the new meters.

- Low level of employees' loyalty and commitment as a result of lack of appropriate incentives or/and job stability for maintenance technicians and meter readers. 30% of 40 tampered meters a week that reach meters workshop are tampered by technicians of Sana'a water utility.

Chapter 6

Suggesting NRW Management for Sana'a Water Utility

6.1. Research Question

What NRW management options should be suitable for the context of Sana'a water utility?

6.2. Research Method

The steps mentioned in this part were conducted after the draft results of the previous objectives have been drawn. The following two parts (6.3 and 6.4) present the methodology used in this chapter in order to supply management suggestions and recommendations for improved NRW management in Sana'a water utility.

6.3. Addressing Real Losses

Literature review was the base of the suggested management options for addressing real losses in Sana'a water distribution system.

6.4. Addressing Apparent Losses

Apparent losses were further analyzed for two reasons: (1) apparent losses are dominant in Sana'a water distribution system and thus, should be prioritized; and (2) reducing apparent losses is always cost-effective (Kingdom, et al., 2006).

Apparent losses analysis was done using four techniques: (1) sub-component analysis for apparent losses was carried out to define its sub-components; (2) problem tree analysis after European Commission (2004) was used to ensure that root causes of apparent losses and illegal use are identified; (3) a social questionnaire was distributed to the utility's customers for the purpose of defining the causes of unauthorized consumption; (4) another questionnaire was delivered to consumers with illegal connections for the same purpose of defining the causes of unauthorized consumption, but here from the illegal users point of view.

6.4.1. Sub-Component Analysis for Apparent Losses

Data handling errors

Customer meter reading in Sana'a water distribution system is implemented using the common approach whereby meter readers visit individual meters to collect readings. This method of meter reading is likely to be susceptible to human errors. The headquarters of Sana'a water utility implemented auditing campaign for the fifth zone in the month of June 2010 to compare it with the consumption of May in order to investigate the meter readings errors. The headquarters chose the fifth zone because corrupting practices among meter readers are common to non-negligible extent. Putting that in mind, meter readings of the fifth zone were obtained from Sana'a water utility for the month of June, 2010 to compare the consumption in this month to the month of

May, 2010 in order to verify the accuracy of meter readings submitted by meter readers for billing purposes.

Accordingly, when analyzing the readings of the fifth zone, the readings that showed unrealistic variances were regarded as erroneous readings after Mutikanga, et al. (2010). Erroneous readings then were categorized into two groups; losses (negative due to corrupting practices or errors) and profits (positive due to reading approximation). The net erroneous readings were sorted to either losses or profits. If the net erroneous readings are losses, total losses then were considered as the volume of data handling errors in M^3.

For the rest zones, Sana'a water utility's headquarters estimates data handling errors at 3% of the system input volume (makes up 4.95% of the consumption in 2009). Therefore, a weighted average for the zones based on number of service connections per each zone was identified to present the volume of corrupting practices and data handling errors in Sana'a water utility.

Customer meter inaccuracies

Meters workshop in Sana'a water utility receives two types of meters; stopped and tampered meters, and meters that are working but complained about to have over-registration. About six meters a week are received in meters workshop in Sana'a water utility as complained to have over-registration, but tests reveal that they are working properly with slight under-registration. Data of these meters were targeted to estimate customer meter inaccuracies in Sana'a water distribution system. The workshop estimation based on these data is that customer meter inaccuracies are around 7%. This estimation was built on the results of tests on the workshop; not documented, though. Test results show that meter accuracy was recorded as 85%, 95%, and 97% for amount

of meter that makes up 30%, 50%, and 20% of the total number of meters received respectively. Accordingly, customer meter inaccuracy is assumed at 7% of billed metered consumption and 4.24% of system input volume based on data of 2009 for Sana'a water distribution system.

Unauthorized consumption

Unauthorized consumption is then computed by subtracting the volume of data handling errors and customer meter inaccuracies from the volume of apparent losses. Further, an estimation of the number of illegal connections was estimated through dividing the volume of unauthorized consumption by water consumption for the service connection based on per capita consumption of 61.4 L/day and average number of people per connection as 13 persons.

6.4.2. Social questionnaire

Purpose

The main purpose of the social questionnaire was to investigate the underlying causes of unauthorized consumption. Besides, assessment of the service level as an indicator of customer relation with Sana'a water utility was included to the questionnaire.

Design

The questionnaire was semi-structured interview with one part of closed-end quantitative answers and one part of qualitative free answers (Appendix.4). The questions were formed, tested, then modified in a simple wording style; further, conducted in the slang language to ensure understanding of the questions.

Consideration has been made to informed consent and confidentiality guidelines that are promoted by international compilation of human research protections (Office for Human Research Protections, 2010) to protect rights of the interviewees, the research

purpose, confidentiality of records, and voluntary participating were highlighted at the beginning of the questionnaire.

Population

The target group of the social questionnaire is those served by Sana'a water utility in its five administrative zones. Households were targeted and those who are in charge of their families were preferred in both male and females. As social constraints prevent giving access to women at households, amount of questionnaires were conducted in Sana'a University to increase gender representativeness. This step, although influences the sample characteristics, increases "realisticness" level of data as women in Sana'a city are likely to be more affected by the level of water service and more frank for expressing real causes than men.

Zones where there is no water service provided by Sana'a water utility were disregarded in the questionnaire design and not targeted in the implementation phase. Therefore, all the populations were ensured to be from the target group of the social questionnaire.

Sample Size

The sample size required for the social questionnaire was indentified from Sample Size Lookup Table after National Audit Office (2000); The sample size at 95% population percentage, ±4% precision, and 95% confidence level is 114 samples. Since the questionnaire is implemented through interacting interview; no increase for the sample has been made for contingencies such as non-response samples. Eventually, the total recovered questionnaires were 114.

Sample Method

Simple random sampling was chosen for the social questionnaire as it gives equal chance of selection among the population. The questionnaire was conducted in the fife

administrative zones of Sana'a water utility to random samples to assure that all the population has an equal chance of selection.

6.4.3. Illegal users' questionnaire

The aim of the illegal users' questionnaire was to investigate the reason of this phenomenon in Sana'a water distribution network, but this time from the view point of illegal users themselves.

The questionnaire was structured interview with closed-end quantitative answers and one part of qualitative free answer (Appendix.5). The questions were formed in a simple wording style since the questionnaire will be reached to illegal users through a third party. Confidentiality has been quarantined and maintained to the respondents in the implementation and analysis phase. The size of sample is not known; however, ten respondents were identified to be targeted in the first and second administrative zones in Sana'a water utility. Although acceptance has been gained at the beginning, only four questionnaires were recovered due to lack of trust on some mediators. Four samples are too low to generate and generalize a conclusion of the reasons underlies illegal use; however, this questionnaire hand in hand with the social questionnaire should give a picture of the general reasons' direction for illegal water use in Sana'a water utility. It is worth to motion that questions related to reasons of illegal use were added to the awareness questionnaire to present the view of the employees on the illegal use reasons.

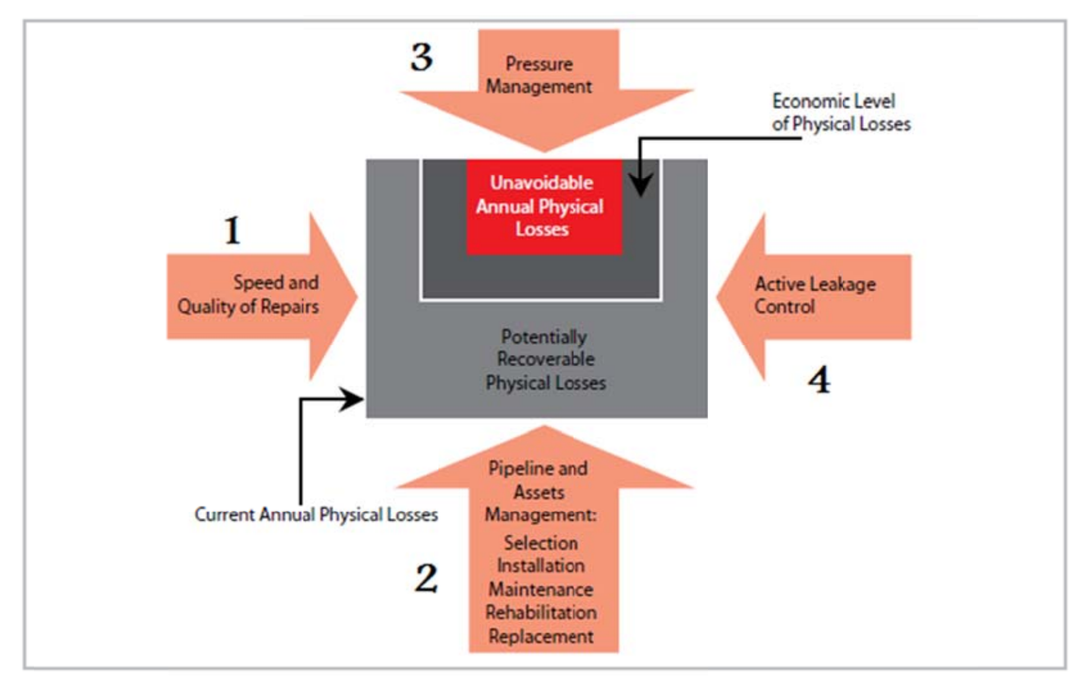
6.5. Results and Discussions

6.5.1. Real Losses Management

Although this part should be repeated in the recommendation chapter, here a discussion of why priorities of leakage management are set in a certain order.

There are four main pillars for a successful leakage management. Figure 6.1 shows how these four billers squeezing the rectangular of current level of real losses in a certain network towards the smaller rectangle of unavoidable annual real losses where real losses could not be minimized any more. It should be noted that all these four billers should work hand in hand to supply successful leakage management. However, their establishment in Sana'a water distribution system should be according to the special conditions of both Sana'a water network and Sana'a water utility. A suggested sequence for establishing these pillars in Sana'a water utility is as follows:

The first step for a better leakage management in Sana'a water distribution system is through enhancing the speed and quality of repairs as it is a cost-effective procedure. Although Sana'a water utility has established DCMMS system for leakage management, the system is still young and lacks four elements: (1) the system achieved low level of average repairing time in 2009 (123 h/day), and there is a lot of potential for improvement; (2) it lacks categorizing the leakages into leakage types (e.g. service



ı'a water

connections, mains, ..) ; (3) there is no breakdown for the repairing time into awareness time, locating time, and repairing time; and (4) the system lacks evaluating procedures for the quality of work done for repairing leakages. Once these elements are integrated in the system, advanced leakage analysis could be achieved, and thus better level of speed and quality of repairing could be fulfilled.

The second step of leakage management in Sana'a water distribution system is the most difficult one; assets management. Although Sana'a water utility has failed in many trials for zoning its network, no assets or network management could be progressed without this procedure. Zoning principle as well as District Metered Areas (DMA) must be installed in Sana'a water distribution system. If the utility could not fulfill that, then, here comes the role of the private sector; to help the utility with a new technology to exceed the technical constraints for applying zoning and DMAs in the water system. Once achieved, zoning Sana'a water network would contribute significantly to a more effective network operating, rehabilitating, and maintaining.

The third step is pressure management in the sense of management rather than reduction. Pressure management requires DMAs to allow controlling and sustaining the required pressure by means of valves and pressure reducer valves. Although pressure management is considered to be the most effective tool for leakage reduction in short-term intervals, it does not have such a reduction potential in Sana'a water distribution system whose pressure is likely to be at too low level for reducing. However, pressure management in the sense of sustaining the planned pressure in the DMAs and controlling transient and altitudes of the network would lead to leakage reduction in Sana'a water distribution system.

The forth step is monitoring network flows through bulk metering in DMAs where no leaks are reported. Active leakage control should determine where leak location activities should be undertaken in proactive rather than reactive leakage management. Although this seems to be advanced for the case of Sana'a water distribution system, it is considered internationally as cost-effective and efficient leakage management. It reaches unreported and invisible leaks before they got worsened limiting the total volume of water lost.

Once these four steps are implemented in Sana'a water utility in whatever order, the four techniques should work simultaneously to give a synergetic effect on leakage reduction and thus supply efficient management.

6.5.2. Apparent Losses Management

6.5.2.1. Sub-Component Analysis

Data handling errors

Sana'a water utility estimates data handling errors at 3% of system input volume which makes up 4.95% of metered consumption based on 2009 data. Further auditing campaign has been conducted by the headquarters of Sana'a water utility in June, 2010 to the fifth zone with 23044 customers due to recognizable corrupting practices by meter readers in the fifth zone. A statistical analysis for audit data reveal that data handling errors and corrupting practices in the fifth zone stands for 7.8% of metered consumption (Detailed analysis is provided in Appendix.6). This percentage was weighted to number of customers for the zone and an average of 5.71% was estimated to be volume of data handling errors out of metered consumption as shown in Table.6.1. This percentage makes up 3.46% of the system input volume. This result is realistic as it goes along with the default values suggested by Mutikanga, et al. (2010)

for utilities in developing countries with similar practices' category of Sana'a water utility.

Table.6.1 Errors of Data Handling and Corrupting Practices of Meter Readings in SWSLC		
unit	Out of Metered Consumption	Out of System input volume
%	-5.71	-3.46
M^3/day*	2112.92	
*For 2009, Metered consumption = 37003.84 M^3/day; system input volume = 61069 M3/day		

Unauthorized consumption

Volume of unauthorized consumption is determined by deducting volume of data handlings errors (3.46% of system input volume) and customer meters inaccuracies (4.24%) from the volume of apparent losses (26.57%). Accordingly, volume of unauthorized consumption makes up 18.87% of system input volume. Table.6.2 and Figure 6.2 show the breakdown of apparent losses including the volume of unauthorized consumption.

Table.6.2 Apparent Losses Breakdown		
Type of loss	Loss out of System input volume (%)	M^3/day
Apparent Losses	26.57	16226
Customer Meter Inaccuracies*	4.24	2590
Data Handling Errors	3.46	2113
Unauthorized Consumption	18.87	11523

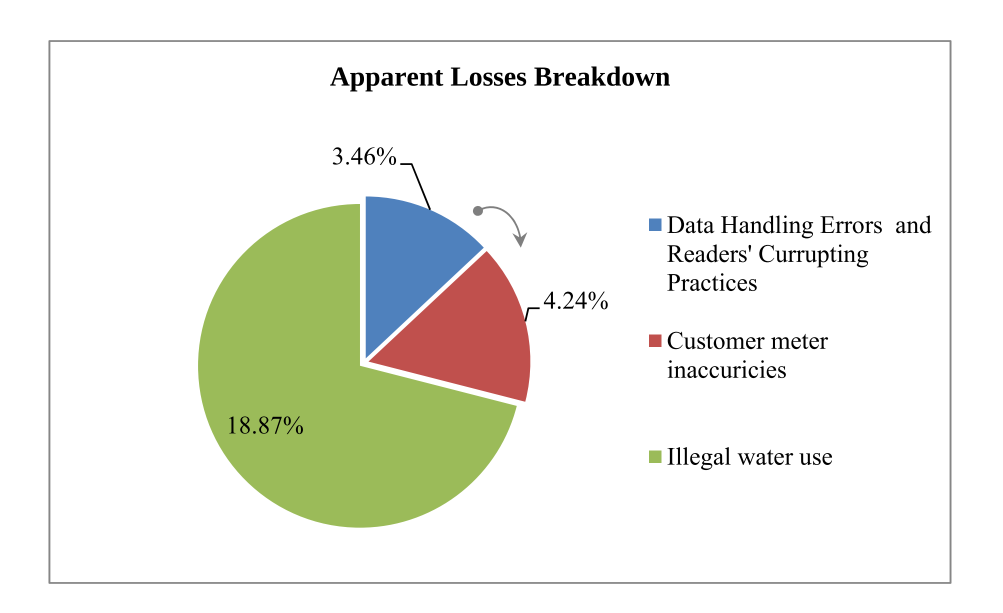


Figure.6.2: Apparent losses Breakdown as % of System Input Volume

With 13 people served by each service connection and per capita consumption of 61.4 L/day, the number of illegal connections is 14437 connections. This number includes bypasses, tampered and zero meters, and illegal connections. Therefore, 16% of customers of Sana'a water utility use unauthorized water through illegal connections, bypasses and tampered and stopped meters. This reveals that illegal water use in Sana'a water distribution system tends to be a phenomenon rather than limited practices and the reason for such a phenomenon should be defined. The following parts attempt to answer this query in order to supply a solution for this phenomenon.

6.5.3. Causes of Illegal Water Use

6.5.3.1. Problem Analysis of Illegal Water Use

Figure 6.3 shows a tree problem analysis for causes of illegal water use in Sana'a water distribution system. This figure is part of a bigger problem tree analysis for all components of apparent losses in a suggested form of IWRM tree problem analysis in Appendix.7. Figure 6.3 shows that the general frame of illegal use causes lies within six main causes: (1) poor customer-utility relation; (2) lack of monitoring; (3) high competition for water as customers use illegal connections to suck water from the network within the time of service provision; (4) lack of employees' loyalty and commitment; (5) poverty; and (6) corrupting practices.

Determination of how much each of these causes contribute to the problem of illegal water use in Sana'a water distribution system could be drawn by the results of social and illegal users' questionnaires and also from results of current practices of Sana'a water utility in Chapter 5.

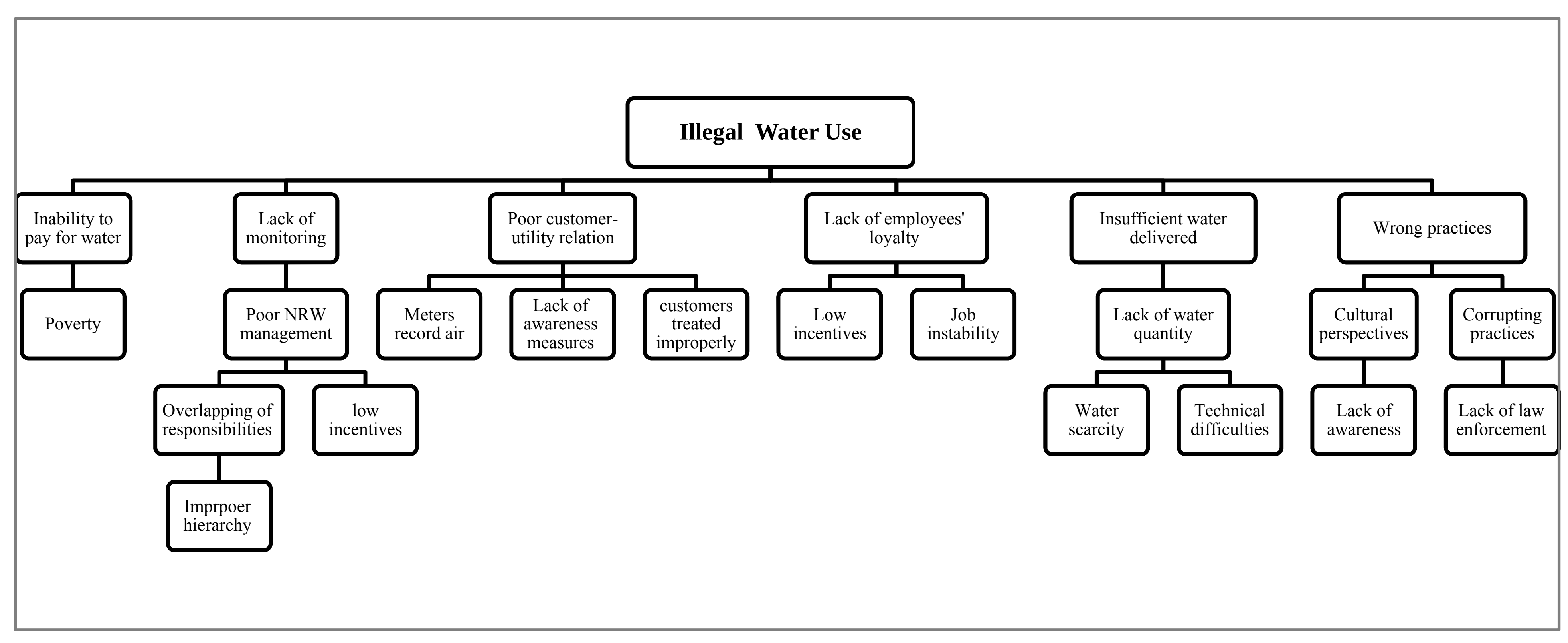


Figure.6.3: Problem Tree for Illegal Water Use in Sana'a Water Distribution System

6.5.3.2. Social questionnaire

Sample characteristics

A questionnaire was interviewed in areas covered by water service of Sana'a water utility in its fives zones. The target group was households that covered by water service of Sana'a water utility. The main purpose of the questionnaire was to investigate the causes of illegal water use in Sana'a water distribution system as unauthorized consumption makes a significant volume of NRW.

Figures 6.4.A-F show the characteristics of the questionnaire's sample. Most of the respondents live in houses (67%), the other live in apartment (25%), and only 4% live in villas as shown in Figure 6.4.B. This indicate the income level and economic situation of the sample which show that most of the respondent have middle class income level and thus live in houses rather than apartment according to the living pattern in Sana'a city.

The prevalent gender of the respondents are male and about 35% of the respondents are female as shown in Figure 6.4.D. This percentage is considered high as social constraints limits the access to interview female at households. This percentage was due to conducting some interviews in the Sana'a University to allow access to gender perception presentation in the questionnaire.

Figure 6.4.E shows that almost half of the respondents are with age between 20-30 years. These age categories are usually of educated people that consider objectiveness of the research process. The rest are older than 30 which indicate that all sections of the society are presented in term of age distribution.

The questionnaire's Results

Results show that more than half of the respondents believe that illegal water use phenomenon is prevalent (Figure 6.5). However, only 35% of the respondents state that they know illegal water users (Figure 6.6). This is due to sensitivity of the question that might imply potential harm for illegal water users whom respondents know.

As shown in Figure 6.7, the main three causes of illegal water use in Sana'a water distribution system are lack of monitoring, high water tariffs, and lack of water availability in the network. The main solution respondents suggest is monitoring measures to be implemented by Sana'a water utility (Figure 6.8). As Sana'a water utility tends to utilize the religious position for limiting illegal use, results show that it would contribute to its limitation but to the expected extent (Figure 6.9).

Sample characteristics

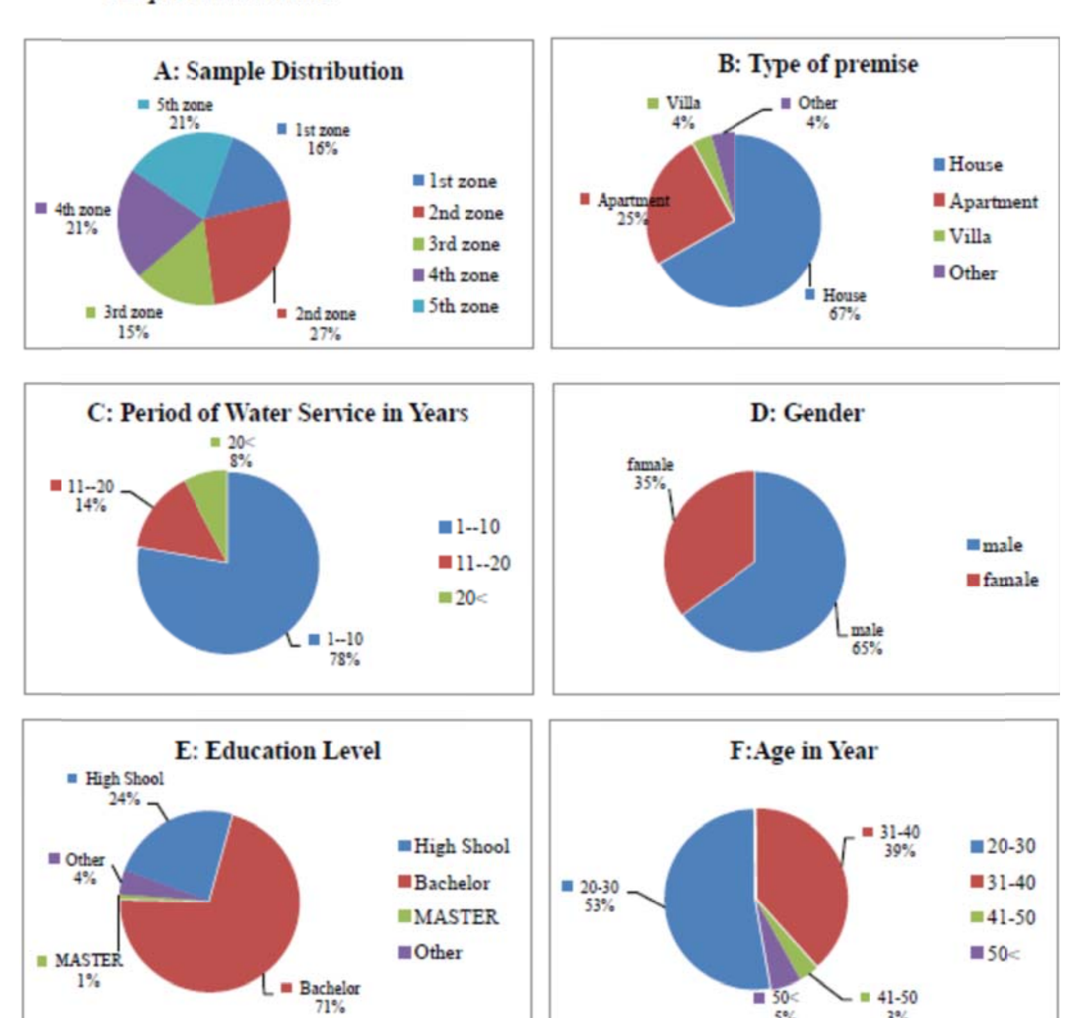


Figure.6.4 (A-F): Social questionnaire- Sample Characteristics

Illegal use causes and prevalence

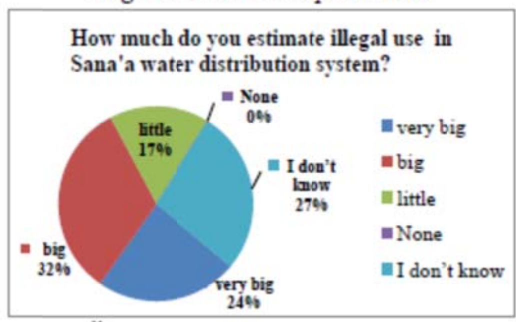


Figure6.5: Illegal use prevalence

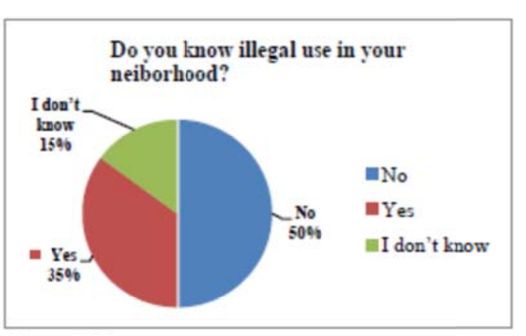
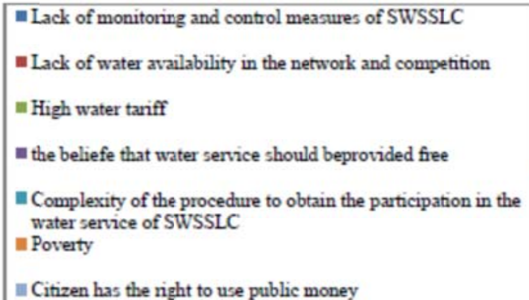


Figure.6.6: Illegal use prevalence



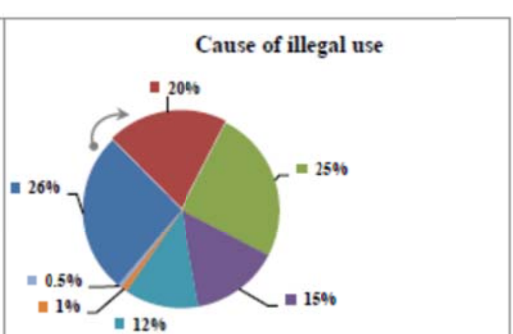


Figure 6.7: Illegal use causes

Solution for illegal use

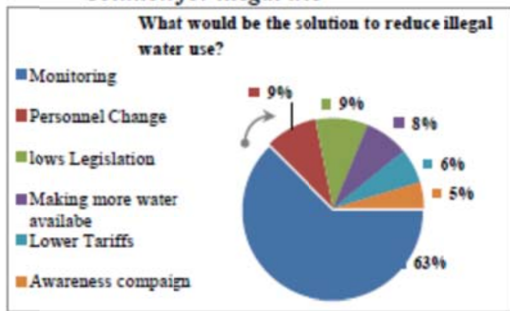


Figure 6.8: Solution for illegal use

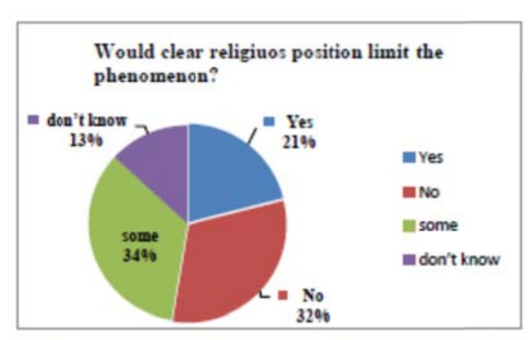


Figure6.9: Influence of religious position on illegal us

6.5.3.3. Illegal users' questionnaire

The purpose of this questionnaire was to get a closer look at the reasons of illegal water us through reaching the illegal water users themselves. Due to difficulties to reach the sample, only four samples out of ten identified samples were recovered. Due to lack of sufficient sample size and inability to reach the illegal users directly, neither qualitative nor quantitative tools could be applied to generate results from the questionnaire. However, the scope of reasons of the illegal water use in Sana'a could be recognized by these answers. Appendix.8 shows the sample characteristics and the results of main questions of illegal water users' questionnaire. However, it is worth to mention that results of this questionnaire showed that poverty is the main cause and then, followed by ill-treatment of the employees of Sana'a water utility, lack of water, and the air in the network that is recorded by water meters as shown in Figure 6.10.

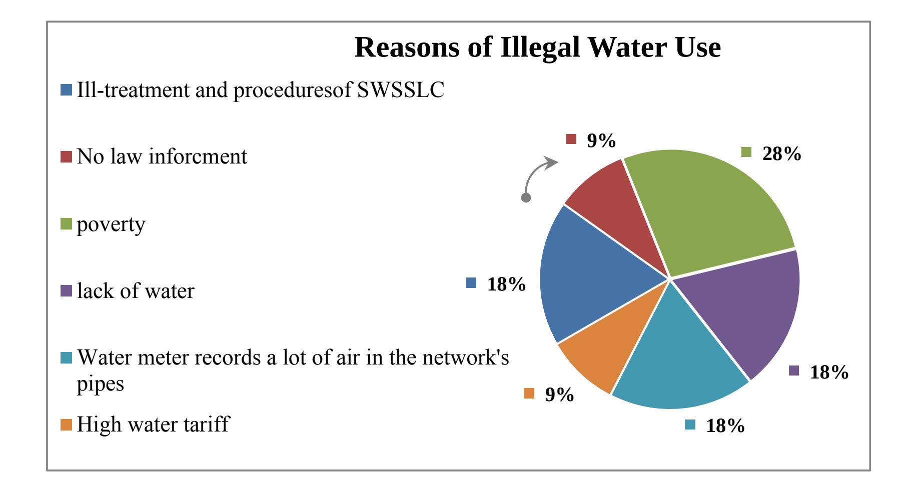


Figure 6.10: Illegal users' questionnaire: reasons of illegal water use

6.6. Conclusions

6.6.1. Real Losses Management

- A suggested order for leakage management techniques in Sana'a water distribution system is: (1) improving the speeds and quality of repairs through optimizing the current system of DCMMS; (2) asset management; although most difficult part, it is the focal step towards leakage management. The establishment of zoning principle and DMAs is a must in Sana'a water distribution system. Since the utility failed in many trials, it is the role of the private sector to provide a more proper technology for DMA establishment; (3) pressure management in the sense of management rather than reduction; (4) active leakage control through metering and monitoring the flow of DMAs to allow reaching the unreported or invisible leaks.

6.6.2. Apparent Losses Management

- Further analysis for apparent losses showed that illegal use makes up 50% of NRW volume. The results showed that among the apparent losses (26.57% of system input volume), customer meters inaccuracies and data handling errors stand for 4.24% and 3.46% respectively. Unauthorized consumption is determined at 18.87%. Hence, the final form of the standard water balance is shown in Figure 6.11.
- 16% of customers of Sana'a water utility use unauthorized water through illegal connections, bypasses, and tampered and stopped meters. This in turn indicates that illegal water use in Sana'a water distribution system is a phenomenon rather than limited practices.

Water Balance (%) of Sana'a Water Distribution System (2009)

System Input Volume 100 %	Authorised Consumption 61.76 %	Billed Authorised Consumption 61.25 %	Billed Metered Consumption 60.59 %	Revenue Water 61.25 %
			Billed Unmetered Consumption 0.66 %	
		Unbilled Authorised Consumption 0.51 %	Unbilled Metered Consumption 0.20 %	Non-Revenue Water 38.75 %
			Unbilled Unmetered Consumption 0.31 %	
	Water Losses 38.24 %	Apparent Losses 26.57 %	Unauthorised Consumption 18.87 %	
			Metres Inaccuricies and Data Handling Errors 7.70 %	
		Real Losses 11.67 %		

Figure 6.11: Water balance including sub-component of apparent losses

- Causes of apparent losses should lie within six main reasons: (1) poor customer-utility relation; (2) lack of monitoring; (3) insufficient water as customers use illegal connections to suck water from the network within the time of service provision; (4) lack of employees' loyalty and commitment; (5) poverty; and (6) corrupting practices.
- Among the above reasons, the social perspective is that lack of monitoring, not appropriate tariffs, and insufficient supply are the main reasons for illegal water use.
- Many reasons mentioned in the social questionnaires imply the low level of customer-utility relation that is also concluded in Chapter 5. For example, complexity of the utility procedures, ill-treatment of the employees of Sana'a water utility, and the air in the network that is recorded by water meters.

- The solution of illegal water use from the social perspective is implementing more effective monitoring measures, and working on the employees' loyalty; Or as they stated: personnel change.

Chapter 7

NRW Monitoring in Sana'a Water utility; Performance Indicators

In this chapter, the Infrastructure Leakage Index (ILI) as a recommended indicator of physical losses by several international agencies would be familiarized. Afterwards, the rest of NRW performance indicators will be determined and presented using NRW softwares.

7.1 Research Question

- What is the value of Infrastructure Leakage Index (ILI), for the real losses component of NRW in the water distribution system in Sana'a water utility?

7.2 Research Method

Infrastructure Leakage Index is determined by applying Equation 2.2 and with adapting Equation 2.3 to Equation 1.7 which has a correction for low pressures as follow:

$ILI = CARL/ UARL$ ……………………………………………………...…..Eq.2.2

$UARL\ (liters/day) = (18 \times Lm + 0.8 \times Nc + 25 \times Lp) \times P \times Cp$……..Eq.7.1

Where

CARL = Current annual real losses
UARL= Unavoidable annual real losses
Lm = Mains pipes length (km);

Nc = Number of service connections;
Lp = Total length of private pipe, property boundary to customer meter (km);
P = Average pressure (m)

Cp: correction coefficient of pressure once pressure is less than 25 m.

Current annual real losses (CARL) are calculated in previous objectives of the research. Other data such as Lm and Nc were obtained from Sana'a water utility through analyzing the network in the Arc GIS software Packages. Lp was set as zero for the case of Sana'a water network according to Appendix.1 as the configuration of the water meter is outside of the customer building, and thus the private length for the customers in Sana'a water network is zero.

For the purpose of calculating the average pressure, Lambert and Taylor (2010) have suggested a systematic approach through; (1) calculating the weighted average ground level against the number of service connection for each distribution area; (2) measuring the average zone pressure for each area; and (3) calculating the weighted average pressure for the aggregated zones.

For calculating the average pressure in Sana'a water network with consideration to the supply pattern similar approach was implemented:

7.2.1. Calculating the Average Ground Level

For calculating the average pressure in the network, the ground elevation difference of the Average Zone Point (AZP) and the pumping station point should be considered. Since there is no contour map for the network in Sana'a water utility, the Average Zone elevations were determined through three steps:

(1) The elevations of the wells within the distribution areas in the network were obtained from Sana'a water utility, and then the difference in elevation from the wells in the subject area and the pumping station elevation were calculated.

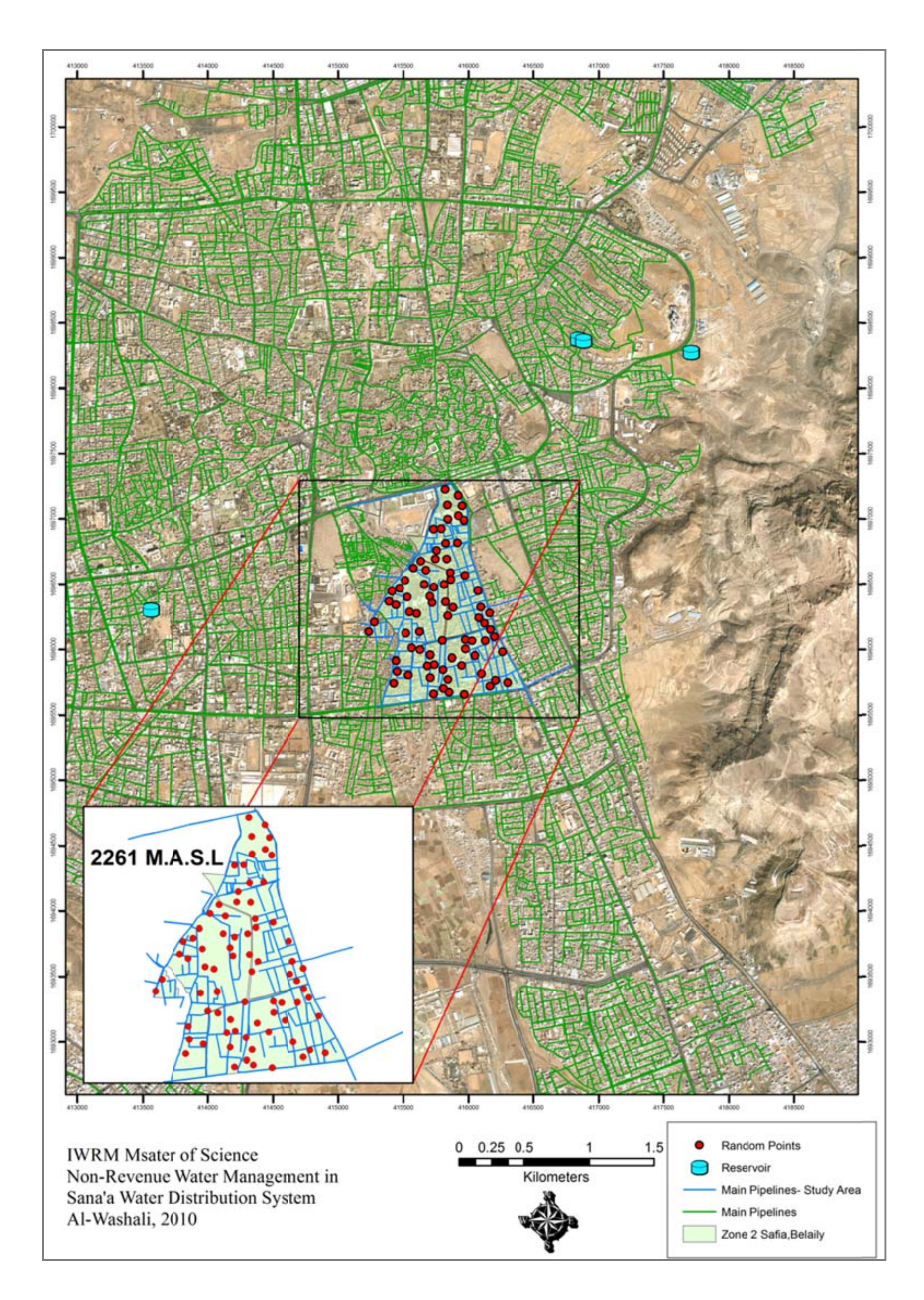
(2) For the reason that the wells are not located in the average zone point, the Digital Elevation Model (DEM) for Sana'a city was integrated with the network data in the Arc GIS Software. Using the Arc GIS should provide more sensible and representative elevation variance as it generates numerous random elevation points for the whole area rather than certain points in the area. Then, the software computes the average elevation of the area. Figure 5.1 and Figure 5.2 show samples of how the average zone elevation is computed using the Arc GIS software; particularly the tool "generate random elevation points".

(3) Since the DEM accuracy might not be appropriate, the elevation of the wells that are obtained from Sana'a water utility were compared to the elevations from the DEM to assess the accuracy of this process. Doing so showed that the differences between the respective elevations were in the range of 1-2 m. This range of accuracy is accepted when calculating the average zone point for the initial average pressure in the network because the suggested approach by Lambert and Taylor (2010) does not take into count the friction losses that should have higher source of errors. Therefore, it was assumed that accuracy of about ± 1 – 2 m was accepted when calculating the average zone point for "initial average pressure" determination in Sana'a water network.

7.3.2. Calculating the Average Pressure

The pumping pressure data for areas that are supplied from the main pumping station were taken and the rest were estimated by mangers and staff of the utility through long discussions. So, the pressure data at the pumping stations were all defined. Consequently, as the average zone elevations were already determined, the average pressure for each area in the pumping station was reduced due to elevation difference.

Eventually, the operating pressure for each distribution area was weighted to the number of service connection, and finally the operating average pressure in Sana'a water network was determined.



7.3.3. Defining the adjusted UARL

As discussed in Chapter two, when calculating the Unavoidable Annual Real Losses (UARL) for the purpose of determining the ILI, UARL should be adjusted for the intermittent supply by dividing UARL by the average number of supply hours per day (Ranhill and USAID, 2008). For this reason, the distribution pattern of water supply in Sana'a network should be considered for each distribution area. The area name, the number of service connections per area, supply time in days per week, and supply times in hours per day should be determined to define the average supply time in the network. These figures are available in Sana'a water network apart from the service connection for each distribution area.

To determine the number of connections for each distribution area, the total number of service connections was divided by the total length of mains for the whole network to give the average number of service connection per each km of mains length. Then the length of mains for each distribution area was summed using the Arc GIS software. Afterwards, the number of service connection for each distribution area was determined via multiplying the length of mains for each distribution area by the average number of service connection per km of mains.

The average supply time was obtained from the record of the main pumping station in Sana'a water utility. For the areas that are supplied from wells within the areas and therefore, there are no records for their supply time, a discussion was made with the distribution staff including managers and an estimation of the average supply time was defined for these areas.

Eventually, the weighted average supply time for each area was weighted to the number of service connection and thus, the average supply time for whole network in

terms of hours per day was determined. Hence, the adjusted UARL and consequently the ILI was calculated for Sana'a water distribution system.

7.4. Results and discussion

Table.7.1 shows the values of ILI and its variables. The average supply time in Sana'a water distribution system under the supply pattern of 2009 is 4.4 h/day with an average pressure of 30.3 m. Unavoidable Annual Real Losses (UARL) are calculated at 496 M^3/day indicating high technical difficulties of infrastructure management. This value is justified by high density of service connections per length of mains in Sana'a water distribution system. The value of ILI is calculated based on these figures at 14.4. The closer the value to one, the more optimum the management practices of a water utility towards infrastructure water system.

Being 14.4, ILI is very advanced for Sana'a water distribution system when comparing to other cities in the world. A comparison for ILI in Sana'a water distribution system to other cities in the world is shown in Figure 7.2. According to Figure 7.2, Sana'a water utility is managing the network properly. Nonetheless, this is if the operating pressure of the network is 30.3m as the results show.

Table.7.1
Infrastructure Leakage Index for Sana'a water utility (ILI) (ratio)

Average Supply Time [h/day]	4.4
Average Pressure [m]	30.3
CARL - Current Annual Real Losses [M^3/day]	7127
UARL - Unavoidable Annual Real Losses [M^3/day]*	496
ILI (CARL/UARL)	**14.4**

* at Nc = 88936 and Lm = 977 km

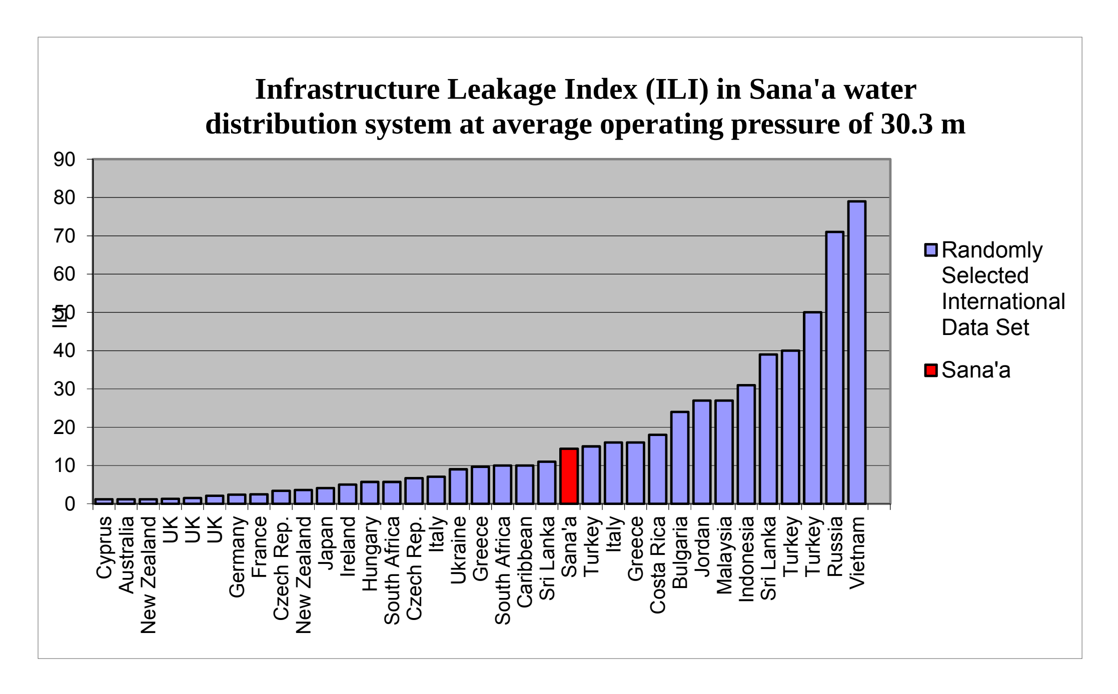


Figure.7.2: Infrastructure Leakage Index (ILI) in Sana'a Water distribution system at average operating pressure of 30.3 m. Source of Data for other cities: The Free Water Balance Software V3.00

Having an average operating pressure of 30.3m in Sana'a water utility is likely to be not realistic to present the operating pressure of the network. In such a case, the value of ILI is fallible.

It is likely that operating pressure calculated is not accurate for one reason: average operating pressure in Sana'a water distribution system was calculated based on the guidelines of Lambert and Taylor, (2010) who recommended that the friction losses could be negligible for initial calculation of average operating pressure. The friction losses and pressure minor losses in Sana'a water distribution system are likely to be significant since results revealed that the density of service connections in Sana'a water network is 91 service connections per km of mains which is very high when comparing to typical water network in a European city with 20 service connections per km of mains. This indicates high number of joints and therefore, high level of friction losses that affect water pressure.

ILI- Pressure Manipulation

ILI is dependent on pressure value to a great extent. Figure 7.3 shows that with every decrease of operating pressure by 1 meter, ILI ratio, which should be 1 for optimal network and utility practices, increases 2 values.

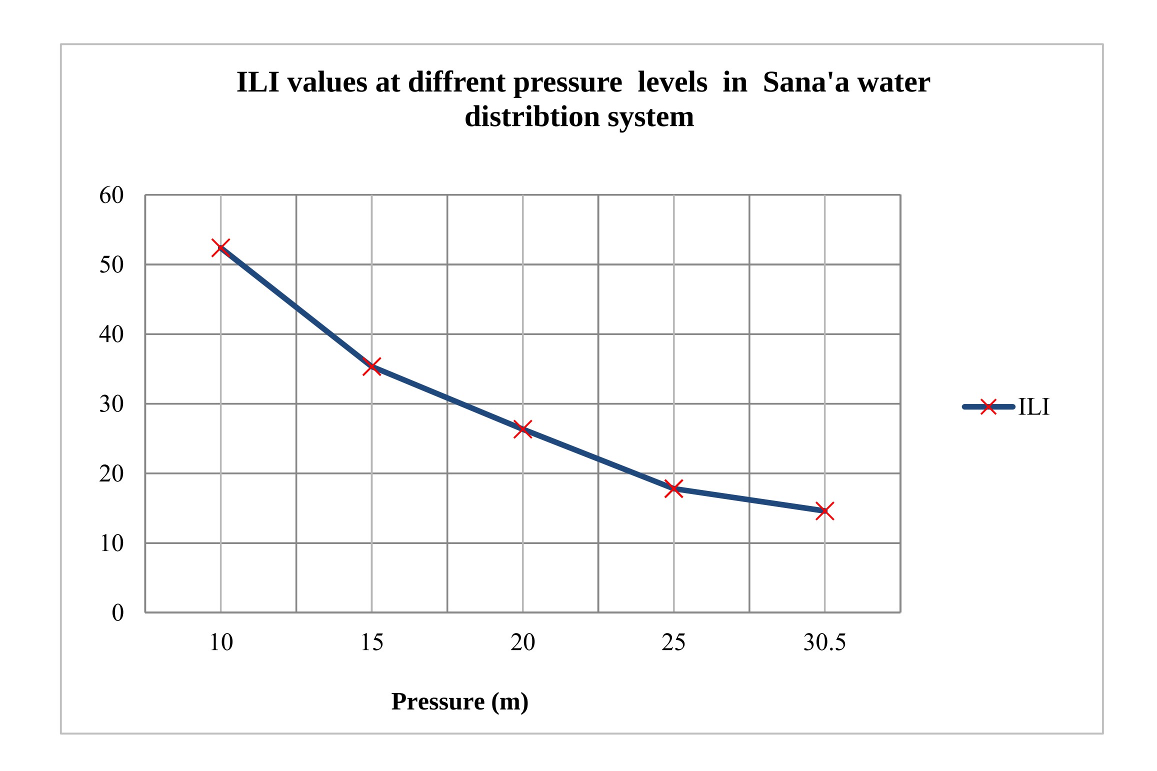


Figure 7.3: ILI values at different pressure levels in Sana’a water distribution system

Giving a real value for average operating pressure in Sana'a water network would indicate the true ILI in Sana'a water distribution system. The only study found that measure the operating pressure in SWSLC is Haidera (1995). When calibrating the network models by measuring the pressure in the pipes, Haidera found that average operating pressure in Sana'a network in 1995 with young network and sufficient water resources back then was about 8 - 15m. Although not recent study, it indicates the level of operating pressure in the network when the network was in better conditions

such as age of the network and water availability. Having average pressure around 10 m, ILI would be around 45 if so Figure 7.2 would be modified to Figure 7.4.

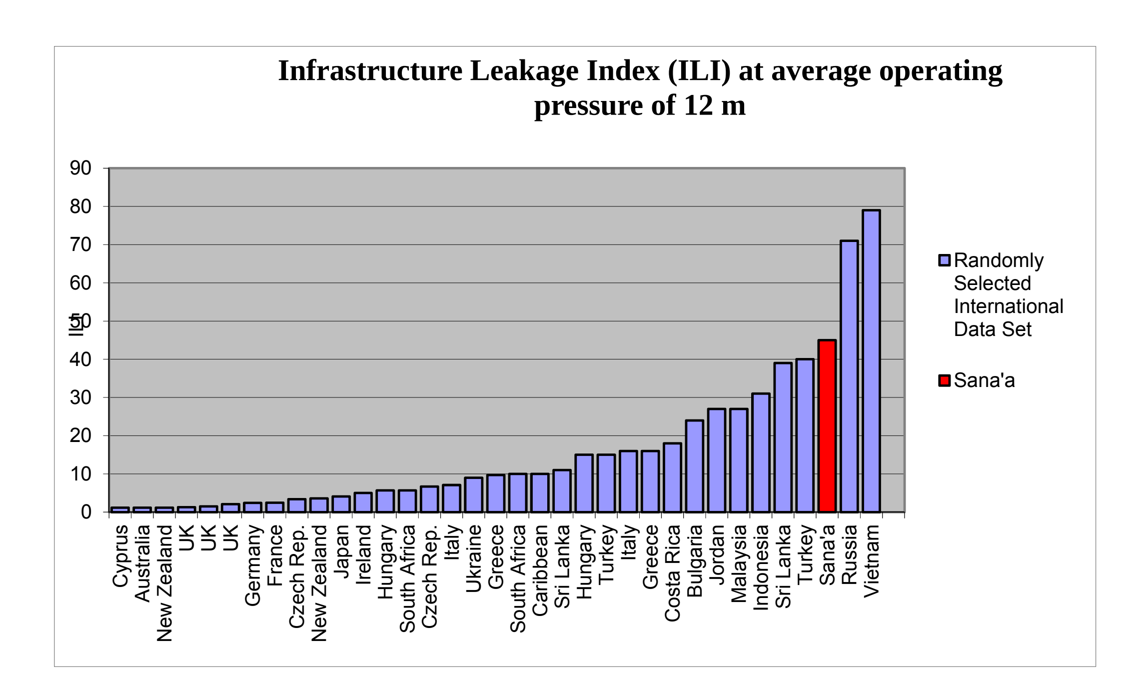


Figure 7.4: Infrastructure Leakage Index (ILI) in Sana'a Water distribution system at average operating pressure of 12 m. Source of Data for other cities: The Free Water Balance Software V3.00

On the other hand, friction losses and minor losses for a network of connections density of 91 connections per km of mains are most likely to be more than 1 meter. If so, ILI would exceed 16 as decreasing the pressure with one meter increases ILI with 2 values. Therefore, ILI in Sana'a water distribution system should be more than 16.

Once ILI value is defined, then it should be interpreted by the real loss assessment matrix developed by World Bank Institute (Table.2.4 in Chapter 2). Consequently, ILI for values between 8 and 16 is classified in C category and for values more than 16 lies in category D for the developing countries. Bothe categories, C and D, require intensifying NRW reduction efforts.

Sana'a water distribution system is categorized either in C or in D category in the real losses assessment matrix with more probability of being in category D. If so, Sana'a

water utility is classified as it uses resources inefficiently, and NRW reduction programs are imperative.

7.5. Other NRW Performance Indicators (PIs)

Main NRW performance indicators for the apparent losses and real losses that are recommended by IWA and AWWA are shown in Table.7.2 and Table.7.3. Losses are expressed in terms of volume per each service connections or per length of mains. Despite the fact that each water utility has its own performance indicators, the most common and recommended ones are ILI for real losses and apparent losses expressed in % of authorized consumption.

While this study could not provide exact figure for ILI as discussed earlier, real losses in Sana'a water distribution system when intermittent supply is considered in the calculations, is 437 L/service connection/day. This value is not influenced by pressure values, and thus could be an alternative indicator that represents the level of real losses in Sana'a water distribution system.

On the other hand, apparent losses make up 43% of the authorized consumption as shown in Table.7.3. This percentage is high due to the fact that apparent losses are dominant in Sana'a water distribution system as discussed in Chapter 4.

Other financial indicators and indicators for level of service are provided in Table.7.4 and Table.7.5. The level of service in Sana'a water distribution system is 4.4 h/day which is low and NRW monetary value is high and standing for 33% of annual operating cost.

Apart from ILI, all these indicators while reflect low performance of Sana'a water utility, does not consider the potential difficulties that the utility might encounter.

Table.7.2 Real Loss Performance Indicators	
Infrastructure Leakage Index (ILI)	14.4*
Liters per Connection per Day (w.s.p.)*	437
Liters per Connection per Day per meter Pressure (w.s.p.)	14
M^3/km mains per hour (w.s.p.)	1.66
*w.s.p.: when the system is pressurized - this means the value is already corrected in the case of intermittent supply * As discussed earlier, ILI for Sana'a water distribution system is likely to have higher value. However, this value is calculated based on pressure of 30.3m.	

Table.7.3 Apparent Loss Performance Indicators	
Apparent Losses expressed in % of Authorized Consumption	**43%**
liters/connection/day	186

Table.7.4 Level of Service	
Average Supply Time [h/day]	4.4
Average Pressure [m]	30.3

Table.7.5 Financial Performance Indicators	
Volume of NRW expressed in % of System Input Volume	**38%**
Value of NRW expressed in % of Annual Operating Cost	**33%**
Liters per Connection per Day (w.s.p.)	1478.3

7.5. Conclusion

7.5.1 Infrastructure Leakage Index in General

- Infrastructure Leakage Index is a robust indicator. Besides measuring the level of real losses, ILI indicates both level of service through taking into consideration pressure level and average time of water service; and management practices towards water distribution network through taking into consideration the conditions of the infrastructure and UARL.

7.5.2 Infrastructure Leakage Index in Sana'a Water Distribution System

- Unavoidable Annual Real Losses in Sana'a water distribution system are high (496 M^3/day). This is due to high density of service connections per length of mains. High UARL indicates high difficulty level of managing infrastructure of Sana'a water distribution system.
- Infrastructure leakage Index in Sana'a water utility lies between 14 and 45 depending on the operating pressure of the network (30.3 to 10 respectively). A specific value for ILI is difficult to be determined with absence of concrete data inputs for estimating the average operating pressure in the network. However, under all scenarios, in accordance to the real losses assessment matrix developed by World Bank Institute, Sana'a water utility should intensify NRW reduction efforts.
- Despite the fact that Infrastructure leakage Index is recommended by many international agencies, yet its application in Sana'a water utility under the current conditions is likely to be difficult due to its data requirements. However, if ILI is to be measure, precise estimation of the operating pressure is required as ILI is highly influenced by the value of operating pressure.

Chapter 8

Non-Revenue Water Awareness in Sana'a Water Utility

8.1. Research Question

How aware are the employees of the NRW-related departments in Sana'a water utility; in its different managerial and operational levels with regard to NRW issues?

8.2. Research Method

8.2.1. Issues to be measured

Employees in NRW-related departments in Sana'a water utility should be aware of what is NRW, what could it mainly affect, and what is the influence of performance and policies of their units and departments on NRW management. Further, those who work in the technical department as well as those who work in the commercial departments in the utility should also know that there are methods existed through which it is possible to assess their job-related components of NRW. It is not necessarily a must that they know how to use these methods; however, they should know that these methods existe. On the other hand, prioritizing and strategizing NRW management is also of importance to be measured. However, it is the responsibility of certain management level and thus, employees in the different managerial and

operational levels do not necessarily have to know these issues. Measuring these issues requires dividing the sample of the population into groups and then a certain group that is involved in NRW planning and strategizing should be targeted in the headquarters of the utility as well as the five administrative zones. Doing so is not within the scope or objective of this research due to time and resources limitations.

Accordingly, NRW awareness measuring of employees in Sana'a water utility covered the following parts: (1) NRW essence, and NRW main impacts; (2) the influence of performance and policies of the different departments in the utility on NRW level; and (3) the existence of assessment methods for NRW break down, and NRW performance indicators;

8.2.2. Forming a Hypothesis

In order to measure the awareness of these issues in Sana'a water utility, several interviews, data collection, reports analysis and field visits have been conducted and then, a primary conclusion of these activities was formed as follows:

"Employees of NRW-relative departments in Sana'a water utility are aware of the NRW essence, and NRW general impacts, but they are not adequately aware of the existence of NRW assessment methods, and NRW performance indicators. Further, they are not aware enough of the impacts and relations of the different departments in the utility on NRW level."

In order to generalize this conclusion for the entire relevant target group in the managerial and operational levels of the utility, a further awareness questionnaire was distributed in Sana'a water utility in its headquarters and administrative zones. Henceforth, this conclusion was treated as a hypothesis that should be tested through conducting awareness questionnaire.

8.2.3. Questionnaire Approach

As recommended by Sundman and Bradbun in 1989, the awareness questions should be softened and treated as opinions because forming acknowledge question as an opinion question reduces the threat to the respondent, and thus they are not asked directly if they possess specific knowledge. Instead, they are asked in a softer format what their opinion on the topic is (Ciochetto and Haley, 1995).

For awareness measuring, Ciochetto and Haley (1995) used statement-opinion questions among three methods for awareness surveys. In statement-opinion questions, respondents were asked to give their opinions about a question's statement; the respondents are asked whether they agree, don't agree, or have no opinion about an explicit statement. For example: a question statement could be:

NRW reduces the utility's revenues. *agree* *don't agree* *have no opinion*

Since, this question has only one true answer (agree), responses with no agreement should be considered as don't know responses.

Therefore, statement-opinion questions approach was adopted and adapted to be the base for measuring NRW awareness in Sana'a water utility. Other methods are test-like and thus should not be appropriate for the case of awareness measuring of employees, operators, and managers in Sana'a water utility.

8.2.3.1. Using Liker Scale

Attitude Likert scaling was the tool for designing the questionnaire since attitude Likert scale is the most widely used research approach within the opinion research (Kloosterand Visser, 2008). According to Kloosterand Visser (2008), Likert scaling is a well-accepted technique for attitude measurement due to its simplicity and reliability.

Likert Scale has three, five, seven, and nine-point scale (Hawcroft and Milfont, 2010). An example of three-point scale is questionnaires with *(Agree, Undecided, and Disagree)*. Five-point scale has the choices of *(Strongly Agree, Agree, Undecided, Disagree, and Strongly Disagree)*. Since the number of points on a Likert scale offered to participants affects the responses (Hawcroft and Milfont, 2010), five-point likert scale was used to enhance measuring the agreement and disagreement level. Besides, according to (Kloosterand Visser, 2008), the typical five-point agreement scale is the best known rating scales. Accordingly, the choices of answers were *(Strongly Agree, Agree, Undecided, Disagree, and Strongly Disagree).*

This approach of measuring awareness of the employees in the organization through statement-opinion questions and Likert scale is also adopted and used by Western Australian General Practice Network (2008).

8.2.4. Questionnaire Design

Based on the questionnaire approach discussed in the previous part, statement-opinion questions with five-point likert scale was the used approach. The statements are fact, literature-based and have only one true answer; agreement answer. Untrue answers were treated as don't know answers. Besides, respondents were asked to choose "Undecided" for points that they don't know or haven't heard about it. Accordingly, Table.8.1 shows the designed interpretation of responses.

In addition, since all statements should have an agreement answer to be true, the respondents might start guessing towards agreement choices. To make the questionnaire looks to have variety of answers, further fourteen opinion answers that do not measure awareness but have real different opinion answers were added to

supply different agreement and disagreement choices in the questionnaire. Then all questions were coded and mixed in the printed version of the questionnaire.

Table.8.1
Responses Decoding

Strongly Disagree	not aware
Disagree	
Undecided	
Agree	aware
Strongly Agree	

8.2.5. Questions Groups

With the purpose of testing the hypothesis, a questionnaire was designed according to the hypothesis structure.

The questionnaire (Appendix.9) contains three main parts. Each part has a group of questions that deal with specific issues of NRW awareness in Sana'a water utility.

(1) The first part of the questionnaire attempts to measure the awareness of what is NRW and its main impacts. This part contains eight questions of which the first question measures the essence of NRW and the rest seven indicators measure the environmental, health, institutional, operational, and financial main impacts. Each indicator is intended to measure one of these impacts. Hence, the questions 1-8 are demonstrating these points.

(2) The second part of the questionnaire deals with the existence of methods for NRW assessment and breakdown. The hypothesis assumes that employees of target group are not aware of the existing NRW calculating methods, and NRW performance

indicators. Consequently, the second part contains four questions (9-12) that talk about the existence of such methods and calculations.

(3) The third part of the questionnaire tries to measure whether the subject employees are aware of the influence of performance and policies of the different departments in Sana'a water utility on NRW level. The hypothesis assumes that subject employees are not adequately aware of the impacts and relations of these departments on NRW level. The questionnaire starts with asking whether NRW issue is only a matter for the technical and commercial departments in Sana'a water utility, then it went further investigating the awareness of respondents with regard to the influence of the projects department, administration department, training department, distribution department, and customer relations departments on NRW level.

Each one of these departments has a contribution on NRW management. For example, studies and projects departments should take into consideration to apply zoning requirements when designing and implementing the new projects. Incentives and job stability affects employee loyalty; training on needs of NRW management is essential; proper water distribution pattern ensures stable operation for the network and minimum level of service; proper customer relations increase the potential of reporting leakages in short time and contribute to limiting the Illegal use phenomenon. Therefore, all the departments are involved in NRW management. Putting that in mind, the third part of the questionnaire contains six indicators (13-18) that deal with the relations and impacts of the different departments in Sana'a water utility on NRW level.

It should be mentioned that this part lacks an indicator for the impact of the financial department on NRW level. Nevertheless, it is assumed that seven indicators for this

part could be representative for the relation and influence of the different departments of Sana'a water utility on NRW management.

8.2.6. Informed Consent and Confidentiality

The international compilation of human research protections provides guidelines for ethics and procedures that protect the rights of the interviewees and sampled people (Office for Human Research Protections, 2010). Based on these guidelines, the research purpose, confidentiality of records, and voluntary participating were highlighted at the beginning of the questionnaire and maintained in the analysis phase.

8.2.7. Population (Target Group)

The target group of measuring the awareness issue in Sana'a water utility, SWSLC, is the technical and commercial departments in the utility headquarter. Besides, the five independent administrative zones that are responsible for the operational tasks in the subdivided network are also a part of this objective's population. In addition, the engineers in of the designs, studies, and projects departments were targeted as well.

In contrast, employees working in irrelative fields were excluded because whether they are aware of NRW issues or not have no impact on NRW management in the utility. An example of those is the employees of specific units such as accountants and editors in the financial department or wastewater technicians in the technical department.

8.2.8. Sample Size

Despite the fact that the questionnaire was eventually distributed to the relevant employees in the NRW-relative units and departments throughout the utility, the following section shows the procedures of calculating the sample size in order to have a representative sample of the employees.

The total number of the employees of Sana'a Water utility is 1242 of which 45% is working in the five independent administrative zones (SWSLC, 2009). According to the figures of the personnel department in the annual report of SWSLC (2009), the ratio of the target group out of the total number of the employees in the utility's headquarter is 29% (195 out of 680). Due to lack of data for the number of the employees in the different units of the other five administrative zones, the same ratio was assumed. Tackling this issue, the administrative zones are likely to have higher ratio of operational employees and thus have a higher ratio of the target group. However, there are a considerable number of employees working in irrelative jobs among the target group in the secretarial work in both the utility's headquarter and the five administrative zones. Therefore, this calculation is the worst scenario trying to avoid underestimation of sample size.

In the light of that, the total number of the target group is 357 employees. Accordingly, the sample size required is taken from the Sample Size Lookup Table after National Audit Office (2000); Figure 8.1.

When deciding the sample size from the table, the population proportion was assumed at 95%. Moreover, it was considered that all the samples would be ensured to be among the target group. Besides, once the questions being of five-order Likert scale, the worst scenario of population percentage should be shifted to a lower percentage (BOLD, 2010).

Accordingly, the sample size at 95% population percentage, ±8% precision, and 95% confidence level is 28 samples which, in turn, stand for 8% of the total population. Afterwards, the sample has been further increased by 25% to account for contingencies such as non-response samples (IFAD, 2010). This action was done

since the target group is likely to be of usually busy people with high work pressure and more likely non-response sample. Finally the sample size has been as 35 samples that count 10% of the total population.

Population Proportion	Precision (at the 95 per cent confidence level)							
	±12%	±10%	±8%	±5%	±4%	±3%	±2%	±1%
50%	66	96	150	384	600	1,067	2,401	9,604
45% or 55%	66	95	148	380	594	1,056	2,376	9,507
40% or 60%	64	92	144	369	576	1,024	2,305	9,220
35% or 65 %	60	87	136	349	546	971	2,184	8,739
30% or 70%	56	81	126	323	504	896	2,017	8,067
25% or 75%	50	72	112	288	450	800	1,800	7,203
20% or 80%	***42***	61	96	246	384	683	1,536	6,147
15% or 85%	***34***	***48***	76	195	306	544	1,224	4,898
10% or 90%	***24***	35	54	138	216	384	864	3,457
5% or 95%	***12***	***18***	***28***	72	114	202	456	1,824

If you are expecting non-response or a difficulty in locating your sample selections then it is prudent to over sample to ensure that the sample size achieved provides the required level of precision.

The figures in ***bold and italics*** denote sample sizes of less than the recommended minimum.

Eventually, fifty questionnaires have been decided to be distributed to enhance the representative of the population In addition, weighted sample distribution was designed to ensure the representativeness of the samples among the employees in the utility in headquarter as well as the administrative zones (Table.8.2).

8.2.9. Sample Method

There are several methods for drawing a sample. The goals and the situations are the base for choosing the sampling method (Antal and Tille, 2011).When choosing the sampling method; the aim should be the balance between the required precision and the available resources (National Audit Office, 2000). The most basic sampling procedures are simple random sampling (Antal and Tille, 2011). Simple random sampling gives every member of the population an equal chance of selection. It produces defensible estimates of the population and sampling error. Nevertheless,

simple random sampling needs complete and accurate population listing (National Audit Office, 2000).

In the research's case, there was no available listing for the target groups. Instead, the questionnaire sample size was weighted according to the number of population in the utility headquarter and administrative zones. Afterwards, visits to the locations of the target groups' offices have been managed after locations investigation. Then the questionnaire was distributed to random samples to assure that all the population has an equal chance of selection.

Table.8.2
Weighted Sample Size and Recovered Percentage

Location	Nr. Of Population	Percentage of Population	Weighted Sample Size	Recovered Samples	Recovered Percentage
Headquarter	195	55%	28	18	64%
Zones	162	45%	22	18	82%
Total	357	100%	50	36	72%
Percentage of Distributed Sample out of the Total Population				**14%**	
Percentage of Recovered Sample out of the Total Population				**10.1%**	

8.2.10. Questionnaire Analysis

The Statistical Package for the Social Sciences (SPSS 13.0 software package) was used for the questionnaire analysis.

First, the questionnaire data was entered to the software. Then, Likert Scale ratings were defined as in Table 8.3. Afterwards, the percentages for each answers' choice out of the total sample were calculated. These percentages were then multiplied by the weight of the choice as in Table.8.3. Then, the mean and standard deviation for each question's answers were calculated. At the end mean and standard deviation for each part (group of questions) were computed.

Table.8.3
Five-point Likert Scale Rating

Source: Abdulfatah , 2008

Choice	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Rate	1	2	3	4	5

After having the mean of each part of the questionnaire, these means were transformed into verbal appreciation according to Table.8.4 as follows:

Table.8.4

Response Average for Five-point Likert Scale

Source: Abdulfatah , 2008

Mean	Response Average
from 1.00 to 1.79	Strongly Disagree
from 1.80 to 2.59	Disagree
from 2.60 to 3.39	Undecided
from 3.40 to 4.19	Agree
from 4.25 to 5.00	Strongly Agree

Eventually, Table.8.4 was translated into Table.8.5 according to the questionnaire approach and the questionnaire design discussed earlier. Finally, the mean of each group of questions was transformed into "aware" and "not aware" expressions. Accordingly, the hypothesis for each part was tested to be positive or negative, and thus the NRW awareness in Sana'a water utility was measured and formed into final statement.

Table.8.5

Awareness measuring table based on rating of five-point Likert scale

Mean	Response Average	Decoding Response
from 1.00 to 1.79	Strongly Disagree	not aware
from 1.80 to 2.59	Disagree	
from 2.60 to 3.39	Undecided	
from 3.40 to 4.19	Agree	aware
from 4.25 to 5.00	Strongly Agree	

8.3. Results

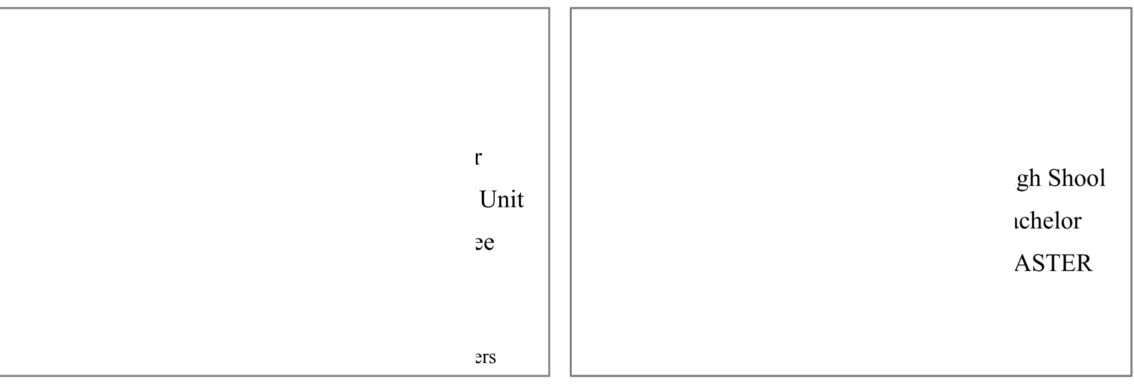
8.3.1. Sample characteristics

A questionnaire was distributed in the technical, commercial, and other relevant units in SWSLC's headquarters and administrative zones. The purpose is measuring the awareness of the employees in these departments with regard to NRW essences, impacts, and influence of the different department of the utility on NRW level. The recovered samples made up 10.4% of the population. Figure 8.2.A-E shows the different characteristics of the sample.

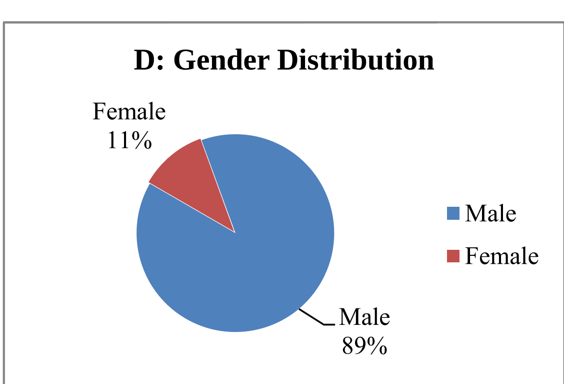
Figure 8.2.A shows that respondents were half from operational levels and almost the other half from managerial levels (56% and 41% respectively). The prevalent

experience period of the respondents is more than six years (72%- Figure 8.2.C). This, in turn, indicates that respondents should be familiar enough with NRW issues in Sana'a water utility.

Figure 8.2.B and Figure 8.2.E show that 70% of the respondents hold qualification of graduate or higher degree, and only 19% of the respondents are older than 40 years old. This would point to the high potential of training in the subject departments.







an 50

8.3.2. The first part of the hypothesis

As shown in Table.8.6, results show that the respondents are aware of the environmental, health, institutional, operational, and financial impacts of NRW; however, they are not aware of the impact of it on the level of service such as lower quality. This indicates to that they do not know the meaning of the term "level of service" or that the question's wording was not appropriate even though it was tested many times before its implementation.

Regarding the level of agreement, the average mean of this part is 3.62 with standard deviation of 1.02 for the eight questions which not very far from "not aware" ranking (3.4) which in turn indicate that respondents prefer not to give extreme statement for things they know.

The final results of this part show that employees of the relevant NRW department in Sana'a water utility are aware of what is NRW, and its main impacts; and thus, the first part of the hypothesis is positive.

8.3.3. The second part of the hypothesis

As shown in Table.8.7, results show that respondents are not aware of the existence of any NRW assessment methods including water balance and minimum night flow analysis. On the other hand, the results show that respondents are aware of the existence of many NRW performance indicators; however, they are not aware of the infrastructure leakage index.

Although the first question that tackled the existence of calculating methods was general, and thus could increase the potential of having aware answer, the result of the question is that employees do not know that there are methods for NRW assessment.

This point is also supported by the general practice of Sana'a water utility, that have no trials of NRW assessment as concluded in Chapter 5.

The average mean of this part is 3.34 with standard deviation of 0.84 of the means of this part. The final results of this part indicate that the subject employees in Sana'a water utility are not aware of the existence of NRW assessment methods and not ware enough of all NRW performance indicators. Hence, the second part of the hypothesis is positive.

8.3.4. The third part of the hypothesis

Results of this part (Table.8.8) are inconsistent. Results indicate that respondents are not aware of the impacts of units in the technical departments on NRW level such as designs and projects department; however, they are well aware that meter readers loyalty and qualification as well as job stability and customer relations are of influence on NRW level. This might reflect the special focus of Sana'a water utility which concentrates on reducing losses for meter readers' errors more than other NRW elements such as real losses.

The average mean of this part is 3.57 with standard deviation of 1.09 which indicate that subject employees are aware of the impacts of performance and activities in the different departments in Sana'a water utility on NRW level. Hence, the hypothesis of this part is negative.

Table.8.6
Awareness questionnaire results-part1
Are the employees of Sana'a water utility that are working in the relevant NRW departments aware of NRW essence, and NRW impacts?

Code of Question	Nr. of Question	Strongly Agree		Agree		Neutral		Disagree		Strongly disagree		MEAN	Std. Deviation	Awareness response average
		Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%			
P2-1-4	**1**	9	25.0	19	52.8	5	13.9	3	8.3	0	0.0	3.94	0.86	Aware
P2-1-1	**2**	9	25.0	13	36.1	8	22.2	6	16.7	0	0.0	3.69	1.04	Aware
P2-1-5	**3**	8	22.2	18	50.0	6	16.7	2	5.6	2	5.6	3.78	1.05	Aware
P2-4-1	**4**	0	0.0	11	30.6	7	19.4	13	36.1	5	13.9	2.67	1.07	Not Aware
P2-1-3	**5**	13	36.1	11	30.6	5	13.9	7	19.4	0	0.0	3.83	1.13	Aware
P2-1-2	**6**	9	25.0	12	33.3	8	22.2	5	13.9	2	5.6	3.58	1.18	Aware
P2-3-4	**7**	8	22.2	22	61.1	3	8.3	2	5.6	1	2.8	3.94	0.89	Aware
P2-3-2	**8**	3	8.3	20	55.6	8	22.2	3	8.3	2	5.6	3.53	0.97	Aware
Average												**3.62**	**1.02**	**Aware**

Table.8.7
Awareness questionnaire results-part2

Are the employees of Sana'a water utility that are working in the relevant NRW departments aware of the existence of NRW assessment methods, and NRW performance indicators?

Code of Question	Nr. of Question	Strongly Agree		Agree		Neutral		Disagree		Strongly disagree		**MEAN**	Std. Deviation	Awareness response average
		Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%			
P2-2-1	**9**	3	8.3	15	41.7	10	27.8	7	19.4	1	2.8	3.33	0.99	Not Aware
P2-2-3	**10**	3	8.3	19	52.8	10	27.8	4	11.1	0	0.0	3.58	0.81	Aware
P2-2-2	**11**	3	8.3	4	11.1	26	72.2	3	8.3	0	0.0	3.19	0.71	Not Aware
P2-2-4	**12**	2	5.6	12	33.3	15	41.7	7	19.4	0	0.0	3.25	0.84	Not Aware
Average												**3.34**	**0.84**	**Not Aware**

Table.8.8
Awareness questionnaire results-part3

Are the employees of Sana'a water utility that are working in the relevant NRW departments aware of influence of performance and policies of the different departments on NRW level?

Code of Question	Nr. of Question	Strongly Agree		Agree		Neutral		Disagree		Strongly disagree		MEAN	Std. Deviation	Awareness response average
		Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%			
P2-3-7	**13**	4	11.1	10	27.8	4	11.1	14	38.9	4	11.1	2.89	1.26	Not Aware
P2-3-6	**14**	4	11.1	14	38.9	8	22.2	5	13.9	5	13.9	3.19	1.24	Not Aware
P2-3-8	**15**	10	27.8	17	47.2	5	13.9	2	5.6	2	5.6	3.86	1.07	Aware
P2-3-1	**16**	20	55.6	12	33.3	3	8.3	0	0.0	1	2.8	4.39	0.87	Aware
P2-3-9	**17**	10	27.8	15	41.7	5	13.9	5	13.9	1	2.8	3.78	1.10	Aware
P2-3-5	**18**	3	8.3	13	36.1	14	38.9	4	11.1	2	5.6	3.31	0.98	Not Aware
Average												**3.57**	**1.09**	**Aware**

8.3.5. The final result

The aggregate statement of the questionnaire's results could be formed as the following:

"Employees of the NRW-relative departments in Sana'a water utility are aware of the NRW essence, and NRW general impacts. They are also aware of the impacts and relations of the different departments in the utility on NRW level. However, they are not adequately aware of the existence of NRW calculating methods, and NRW performance indicators. "

This statement should be generalized to the whole population of the questionnaire as statistical means of responses are with acceptable standard deviation. Further statistical tests that study the variance of the answers' means such as One-Sample Test were obtained from SPSS software. One-Sample Test drew Sig. (2-tailed) for the three parts of the questionnaire with 0.000 which means that results are reliable. The tests prove that the three parts of the questionnaire are a statistical function, and therefore, could be used for extracting a factual statement. This conclusion is due to the use of Likert scaling that is a well-accepted and reliable technique for attitude measurement as pointed out by Klooster and Visser (2008).

8.4. Conclusion

Employees of the NRW-relative departments in Sana'a water utility are aware of the NRW essence, and NRW general impacts. They are also aware of the impacts and relations of the different departments in the utility on NRW level. However, they are not adequately aware of the existence of NRW assessment methods, and NRW performance indicators.

Chapter 9
Conclusions

9.1. Volume of NRW

Conclusion#1

Due to lack of awareness, Sana'a water utility underestimates significantly the volume of Non Revenue Water by discounting unbilled authorized consumption, estimated volume of repaired leakages, and production meters under-registration. These volumes made up 9% of system input volume in 2009.

Conclusion#2

Non-Revenue Water for Sana'a water distribution system in 2009 made up 38.75% of system input volume of which 26.57% is apparent losses; 11.67% is real losses; and 0.51% is unbilled authorized consumption.

Conclusion#3

The volume of real losses in Sana'a water distribution system in 2009 exceeded 5% of the safe yield of Sana'a basin. Using ILI, Sana'a water distribution system should be classified in D category in the real losses assessment matrix developed by World Bank Institute. In accordance to the assessment matrix, Sana'a water utility uses resources inefficiently, and NRW reduction programs are imperative.

9.2. Cost of NRW

Conclusion#4

The cost of NRW is high. NRW in 2009 cost Sana'a water utility 920.6 million YR ($4.3 million) of which 79% are apparent losses, 20% are real losses, and 1% unbilled authorized consumption.

9.3. The Dominant Component

Conclusion#5

Apparent losses are the dominant component of NRW in Sana'a water distribution system. They should be prioritized as they stand for 68.57% of NRW volume. In contrary, real losses and unbilled authorized consumption make up 30.12% and 1.32% of NRW volume, respectively.

Conclusion#6

Further analysis showed that among the 26.57% apparent losses, customer meters inaccuracies and data handling errors stand for 4.24% and 3.46% respectively. Unauthorized consumption is determined at 18.87%. The final figure of the standard water balance is shown in Figure 6.11.

9.4. Volume of Illegal Use

Conclusion#7

Illegal water use in Sana'a water distribution system makes up 50% of NRW volume. 16% of the customers of Sana'a water utility use unauthorized water through illegal connections, bypasses, and tampered and stopped meters. This indicates that illegal water use in Sana'a water distribution system is a phenomenon rather than limited practices.

Water Balance (%) of Sana'a Water Distribution System (2009)

System Input Volume 100 %	Authorised Consumption 61.76 %	Billed Authorised Consumption 61.25 %	Billed Metered Consumption 60.59 %	Revenue Water 61.25 %
			Billed Unmetered Consumption 0.66 %	
		Unbilled Authorised Consumption 0.51 %	Unbilled Metered Consumption 0.20 %	Non-Revenue Water 38.75 %
			Unbilled Unmetered Consumption 0.31 %	
	Water Losses 38.24 %	Apparent Losses 26.57 %	Unauthorised Consumption 18.87 %	
			Metres Inaccuricies and Data Handling Errors 7.70 %	
		Real Losses 11.67 %		

Figure 6.1-Chapter2: Water balance with sub-component of apparent losses

9.5. Verification

Conclusion#8

Accuracy analysis showed that the accuracy of the apparent losses assessment and consequently real losses is ± 1.06% of system input volume assuming that data obtained from Ministry of Water and Environment and Sana'a water utility are accurate.

Conclusion#9

Two further evidences prove the results of NRW assessment through the suggested approach: (1) When Sana'a water utility analyzed the sales' records, it found that more than 50% of its customers consume 1-10 M^3 per month and 33% of the customers lie in the first tariff block consuming 1-5 M^3 per month. The utility doubts that less than 5 M^3 per month is enough for 33% of its customers and assumed that many of these

customers use bypass illegal connections. (2) Records of 2009 showed that among 18445 customers that were disconnected because they didn't pay the bills, only 2705 are reconnected and 15740 customers are still disconnected in spite of the fact that water price from tankers are significantly higher than that provided by Sana'a water utility (\$1.7 and \$0.65 per M^3 respectively). Those who are still disconnected make up 17.7% of the utility customers.

9.6. Causes of Illegal Use

Conclusion#10

Causes of illegal water use in Sana'a water distribution system lie within six main reasons: (1) poor customer-utility relation; (2) lack of monitoring; (3) insufficient water; (4) lack of employees' loyalty and commitment; (5) poverty; and (6) corrupting practices.

Conclusion#11

The poor customer-utility relation is a main contributor to high level of illegal water use. While the social perspective stated that lack of monitoring is the main reason, responses of social questionnaires implied many points related to customer-utility relation. Examples are: complexity of the utility procedures, ill-treatment of the employees of Sana'a water utility, and the air in the network that "could" be recorded by water meters. The air issue was the kick-start of a dwindling customer confidence on Sana'a water utility.

Conclusion#12

There is low level of employees' loyalty and commitment of many technicians and meter readers in Sana'a water utility. This is a result of lack of appropriate incentives or/and job stability.

9.7. Current NRW Management

Conclusion#13

There is no assessment and consequently no prioritizing for NRW components in Sana'a water utility. As a result, NRW management is inefficient. It treats the obvious NRW elements without consideration to its contribution to the volume of NRW. An example, the utility measures focus on reducing meter readers' errors and readers corrupting practices more than illegal water use.

Conclusion#14

Sana'a water utility has made many attempts to reduce real losses; pressure management, zoning, and installing DCMMS system. All encountered with many difficulties and thus did not progress apart from DCMMS system. The system enhanced the reactive leakage management in Sana'a water distribution system. However, there is a lot of potential for further improvement.

9.8. NRW Management Monitoring

Conclusion#15

Unlike the common used percentage indicator, Infrastructure Leakage Index is a robust indicator. Besides measuring the level of real losses, ILI indicates both level of service through taking into consideration pressure level and average time of water service; and management practices towards water distribution network through taking into

consideration the conditions of the infrastructure and the level of unavoidable annual real losses.

Conclusion#16

Yet, the application of Infrastructure Leakage Index in Sana'a water utility under the current conditions is likely to be difficult due to its data requirements.

Conclusion#17

Volume of NRW expressed as a percentage of system input volume as a NRW indicator should not be used on its own; rather, the use of suggested package of real, apparent, and financial indicators by IWA and AWWA allow efficient and comprehensive monitoring. These indicators provided in the free NRW softwares.

9.9. NRW Awareness

Conclusion#18

Employees of the NRW-relative departments in Sana'a water utility are aware of the NRW essence, and NRW general impacts. They are also aware of the impacts and relations of the different departments in the utility on NRW level. However, they are not adequately aware of the existence of NRW assessment methods, and NRW performance indicators.

9.10. The Used Approaches

9.10.1. The Suggested Approach; The Reveres Approach

Conclusion#19

NRW assessment in water utilities with expected high unauthorized consumption is difficult. Top down approach is not recommended as it underestimates unauthorized consumption unless objective estimations for unauthorized consumption are available. On the other hand, the only other option is bottom up approach which estimates NRW through conducting DMAs and zoning principle. This, in turn, besides that it is advanced phase of NRW management as it is part of assets and infrastructure management, it requires advanced technical and financial resources.

Conclusion#20

The suggested approach is an added value in the discipline of NRW management. It provides an alternative methodology of NRW assessment and breakdown for water utilities in countries where unauthorized consumption is expected to be high such as developing countries. In such a case, this approach serves as an alternative for top down approach that developed by AWWA and IWA. The suggested approach uses usually available data of WWTP inflows, per capita consumption, number of people served and billing records of water utilities. All these data should be available in any water utility.

Conclusion#21

The Reveres Approach is sensitive to accuracy of per capita consumption unless other methods of estimating exfiltration rate are used. Besides, although outdoor water use was proved to be with no significant influence on NRW assessment through the reverse approach, it might have other trends in cities where high level of outdoor water use consumption is recorded.

9.10.2. Likert Scale

Conclusion#22

Due to its simplicity and reliability, Likert scale proved to be a robust tool for questionnaire design and analysis.

Chapter 10

Recommendations

10.1. Non Revenue Management in Sana'a Water Utility

10.1.1. NRW Assessment

Recommondation#1

The standard water balance should be drawn at least annually to assess NRW. NRW components could not be prioritized or properly managed without the assessment phase. For this purpose, Sana'a water utility should get use of the free NRW softwares by World Bank Institute and American Water Works Association.

Recommondation#2

Non-Revenue water assessment is not a one end action; rather, it should be a continuous process whose input data to be improved and accuracy of its output water balance to be analyzed.

10.1.2. Real Loss Management

Recommondation#3

A suggested order for leakage management techniques in Sana'a water distribution system is: (1) improving the speeds and quality of repairs through optimizing the current system of DCMMS; (2) asset management; the focal but most difficult step

towards leakage management. The establishment of zoning principle and DMAs is a must in Sana'a water distribution system. Since the utility failed in many trials, it is the role of the private sector to provide a more proper technology for DMA establishment; (3) pressure management in the sense of management rather than reduction; (4) active leakage control through metering and monitoring the flow of DMAs to allow reaching the unreported or invisible leaks.

Recommondation#4

To optimize the existence of DCMMS system, four issues should be improved: (1): achieving shorter average repairing time; the recordered123 h/day in 2009 is still far; (2) recorded leaks should be categorized into leakage types (e.g. service connections, mains,..); (3) the leakage repairing time should be categorized into awareness time, locating time, and repairing time; and (4) the system should have evaluating measures for quality of work done for repairing leakages.

Once these elements are integrated in the system, advanced leakage analysis could be achieved, and thus better level of speed and quality of repairing could be fulfilled.

10.1.3. Apparent Loss Management

Recommondation#5

Apparent loss should be prioritized when designing NRW management strategy as they are dominant and its management is cost effective. Special focus should be paid for unauthorized consumption minimization.

Recommondation#6

For limiting the illegal water use in Sana'a water utility, first, loyalty and commitment of employees, especially technician and meter readers, should be gained and maintained by proper incentives and job stability. Then, monitoring measures for illegal use should

be set; and whenever possible sufficient water should be allocated fairly among the customers within the same distribution area.

Second, customer-utility relation should be improved; communication channels should be established; more appropriate customer treatment should be offered, and regular awareness campaigns should be planned with any management measure related to customers.

Third, customer confidence should be a targeted objective for Sana'a water utility. The air issue should be dealt with by conducting studies for defining the magnitude of the air in the network and its impacts of customer confidence. Then, a cost-benefit analysis should be carried out, and substitution of customer meters should be put among the alternatives.

Forth, once the above points are considered, other measures could be used such as advertisement and rewards for any one report illegal use or as the utility suggest utilizing the religious position for illegal use limitation.

10.1.4. NRW Management Monitoring

Recommondation#7

NRW Percentage as an indicator should not be used on its own as it is highly affected by water consumption and amount of water produced. Instead, it should be planned to make data available for introducing Infrastructure Leakage Index as a real loss indicator that measure the level of service and real losses at the same time. Till that is achieved and after, Sana'a water utility and Ministry of Water and Environment should integrate the package of performance indicators suggested by IWA/AWWA for proper NRW monitoring.

10.1.5. Other

Recommondation#8

Economic Studies

Further studies tackling the economic aspects of NRW management should be conducted with special focus on defining the economic level of leakage. However, apparent losses management is usually cost-effective.

Recommondation#9

Awareness Raising and Capacity Building:

First: awareness measures for the utility employees should be planned for NRW management in general and its assessment in particular; employees should be aware of the existence of NRW assessment methods. Second: the training programs that are designed in participatory approach in the utility should be at the employees' level rather than the managers' level. This would supply more chance for NRW management training among capacity building programs in the utility.

Recommondation#10

Hierarchy Change

First: Commercial unit should be a department on its own. Being a unit in the financial department limited its authorizations and produced confused policies (commercial thinking vs. financial thinking).

Second: Although NRW is an issue of mainly the commercial and technical department in the utility, all the other departments are involved in its management. For this reason and for that there is a natural overlapping of duties and tasks among the units of both commercial and technical departments, it is recommended that an "independent" unit for NRW management to be integrated with the hierarchy of Sana'a water utility to bear the

tasks of collecting NRW data and following up implementation of NRW management measures in all these departments. This unit should have representatives from all the stakeholder departments to ensure access to all relevant departments.

10.2. For Scientific Research

Recommondation#11

There is lack of scientific methods for NRW assessment especially in countries where expected unauthorized consumption is high. Research initiatives for such methods would contribute to save considerable amount of water through better NRW reduction throughout the world. This study attempted to contribute by the suggested approach, Reverse Approach. However, there is big room for improvement; more accurate methods are required for estimating exfiltration from sewers. Analysis for the contribution of the organic material's volume in the suggested equation would also give insights to consider these volumes in the future and then achieve better accuracy of NRW assessment which, in turn, is the most difficult and important phase. Once achieved, water utilities with international cooperation agencies should be and usually are professional of making strategies and the rest of the job.

References

Abdulfatah A. (2008), **Introduction to Descriptive and Inferential Statistics Using SPSS**, (1st ed. in Arabic), Khwarizm, AL-Riyadh.

Al-Hamdi, M. (1997): Case Study XIII - Sana'a, Yemen, in: Helmer, R./Hespanhol, I. (1997), **Water Pollution Control - A Guide to the Water Quality Management Principles.** (1sted), UK: St Edmundsbury Press, Bury St Edmunds, and Suffolk. Printed on the Behalf of World Health Organization, United Nations Environment Program, and Water Supply & Sanitation Collaborative Council.

Al-Hamdi, M. (2000): **Competition for Scarce Groundwater in the Sana'a Plain, Yemen. A study on the incentive systems for urban and agricultural water use**.Published Doctoral Dissertation.A.A.Balkema, Rotterdam.

Al-Kirshi A., and Abbas T. (1998), Protected Agriculture in the Republic of Yemen. In: Mustafa A., AL-Mohammadi A., Abo-Hdid A., and Pencock J.(ED), **Protected Agriculture in the Arabian Peninsula**, Summary Proceedings of an International Workshop 15-18, February 1998, Doha, Qatar, International Center for Agricultural Research in the Dry Areas, Aleppo, Syria. x+104pp.

Al-Washali T., Aklan M., Alwan, M., and AL-Zobairy I. (2006), **Designing Water and Wastewater Networks for the 45th Zone**. Unpublished BSc. Graduation Project, Faculty of Engineering, Sana'a University.

American Water Works Association (AWWA) (2009), **Water Audits and Loss Control Programs**. (3rd ed.), M36 Publication Rewrite, Denver, CO: AWWA Publication.

Amick S., Burgess E., and Selvakumar A. (2000), Exfiltration in Sewer System (EPA publication No.EPA/600/R-01/034), USA.

Arbués F., Garc´ıa-Valiñas M., and Mart´ınez-Espiñeira R. (2003), Estimation of Residential Water Demand: a State-of-the-Art Review. Journal of Socio-Economics, 32: 81–102.

Barrett C., Hamilton B. A., and Arlington V. A. (2010), Water Security & Yemen: Will the Lack of Water Security Lead to a Failed State and a National Security Threat to the US?,**Annual Water Resources Conference**, Pennsylvania, USA, November. 1 - 4, 2010, Abstracts.

BOLD Educational Software (2010), Sample Size Calculator. Retrieved November 28, 2000, from **http://bold-ed.com/calculator.htm**

Brooks, D. (2006) An Operational Definition of Water Demand Management. **International Journal of Water Resources Development**, 22, (4): 521-528

Butler D. and andMemon F. A. (2006), **Water Demand Management.** (1st ed.), UK:IWA Publishing.

Central Statistical Organization (2006), **The General Population, Housing, Establishment Census 2004, General Frame of the Population: Final Results**, Sana'a.

Ciochetto S. and Haley B. (1995). How Do You Measure "Awareness"? Experience with the Lead-Based Paint Survey. Proceedings of **Survey Research Methods**, Alexandria, VA. **American Statistical Association**, 1, pp. 1163-1168.

Cheung P., Girol G., Abe N., and Propato M. (2010), Night flow analysis and modeling for leakage estimation in a water distribution system. In: Boxall J., and Maksimovic C. (Eds), **Integrating Water Systems: Proceedings of the Tenth International Conference on Computing and Control in the Water Industry 2009**. London: Taylor & Francis Group.

Cosgrove, W., and Rijsberman F. (2000) **World Water Vision: Making Water Everybody's Business**. (1st ed.). London: Earthscan Publications.

De BénédittisJ., and Bertrand-Krajewski J.-L. (2004). Infiltration in sewer systems: comparison of measurement methods. **Proceedings of the 4th International Conference on Sewer Processes and Networks**, Funchal, Madeira, Portugal, 22-24 November, pp 301-308.

Department of Water Affairs and Forestry (2004), **Integrated Water Resources Management; Guidelines for Water Conservation and Water Management in Water Management Areas and in the Water Services Sector, South Africa**, Volume 2 – Undertaking a Situation Assessment and Development of a Business Plan in the Water Services Sector. Full Guidelines Version (1st ed.), South Africa.

Dublin Drainage Consultancy (2001), **The Greater Dublin Strategic Drainage Study** (Publication of Dublin City Council, Vol. 4). Dublin.

Ellis, J.B., Revitt, D.M., Lister, C.W., and Buckley, A. (2003), Experimental Studies of Sewer Exfiltration.**Water Science & Technology**, 47: 61–67.

Environmental Protection Agency (2009), **Control and Mitigation of Drinking Water Losses in Distribution Systems**.(EPA 816-D-09-001). Washington DC.

European Commission (2004), Aid Delivery Methods, Project Cycle Management Guidelines (Volume1), Brussels.

Farley M., and Liemberger R. (2004), Developing a Non-Revenue Water Reduction Strategy, Part 2: Planning and Implementing the Strategy, Conference Proceedings, **IWA World Water Congress**, 19-24 September, 2004, Marrakech.

Farley M., and Trow S. (2007),Losses in Water Distribution Networks; A Practitioner's Guide to Assessment, Monitoring, and Control.(2nd ed), UK: International Water Association Publishing.

German Agency for Technical Cooperation (GTZ) (2009) **Yemen Urban Water Supply and Sanitation Sector Reform**, Technical Secretariat (TS)/Reform of the Institutional Framework in the Urban Water and Sanitation Sector, Sana'a.

Gleick P. H., Haasz D., Henges-Jeck C., Srinivasan V., Wolff G., Cushing K. K., and Mann A. (2003) **Waste Not, Want Not: The Potential for Urban Water Conservation in California**, (1st ed.,), appendix b. Hayward, CA: Alonzo Printing Co., Inc.

HalfawyM., and Hunaidi O. (2008), GIS-Based Water Balance System for Integrated Sustainability Management of Water Distribution Assets. Proceedings of **The 60th Annual Western Canada Water and Wastewater Association Conference**, Regina, Saskatchewan, September 23-26, 2008, pp. 1-16.

Harza Engineering Company International and Montgomery Waston Arabtech Jardanah (2006), **Sana'a Water Distribution Systems Improvements**, Design final report, Sana'a.

Hawcroft L., and Milfont T. (2010), The Use (and abuse) of the New Environmental Paradigm Scale over the Last 30 Years: A Meta-analysis. **Journal of Environmental Psychology**, 30: 143–158

Hellegers P. Perry, C. Al_Aulaqi N., Al_Eryani A., and Al_Hebshi M.(2008), **Incentives to reduce groundwater extraction in Yemen**. Report 2008-058, the leading Institute for Social-Economic Research (LEI), Wageningen UR, Netherlands and Belgium.

Haidarah M. (1995) Computer Modeling of Water Distribution Systems with Intermittent Supply; Case Study Sana'a, Yemen. MSc. Thesis E.E. 73, IHE, Delf

Japan International Cooperation Agency (JICA) (2007), **The Study for the Water Resources Management and Rural Water Supply Improvement in the Republic of Yemen, Water Resources Management Action Plan for Sana'a Basin**, Final Report, Sana'a.

Jorgensen B., Graymore M., and O'Toole K. (2009), Household water use behavior: An integrated model. **Journal of Environmental Management** 91: 227–236.

Kingdom, B., Liemberger, R., and Marin, P.(2006),**The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries How the Private Sector Can Help: A Look at Performance-Based Service Contracting**. Water Supply and Sanitation Sector Board Discussion Paper Series Paper NO.8. The World Bank Group.

Klooster P. M., and Visser M. D. T. (2008), Comparing two image research instruments: The Q-sort method versus the Likert attitude questionnaire. **Food Quality and Preference**, 19: 511–518

Lambert A. (2002), International Report on Water Loss Management and Techniques. **Water Science and Technology: Water Supply**, 2 (4): 1-20

Lambert A. (2003), Assessing Non-Revenue Water and its Components: A Practical Approach. **Water 21: Magazine of the International Water Association**, Special Series of IWA Water Loss Task Force: World Best-Practice in Water Loss Assessment, and Reduction Strategies, August: 50-51.

Lambert A., and Taylor R. (2010), **Water Loss Guidelines**. A guideline for the New Zealand Water and Wastes Association; Water New Zealand, New Zealand.

Lambert A. (2010), Personal Communication.

Library of Congress (2008), **Country Profile: Yemen**, Country Studies Series, Federal Research Division, Washington DC.

Liemberger, R., Farley, M. (2004), Developing a non-revenue water reduction strategy, part 1: Investigating and assessing water losses, **Proceedings of IWA 4th World Water Congress**, Morocco, Marrakech 19-24 September 2004.

Liemberger R., and McKenzie R. (2005). Accuracy Limitations of the ILI - Is it an Appropriate Indicator for Developing Countries. **Proceedings of IWA Specialized Conference 'Leakage 2005'**, Halifax, Nova Scotia, Canada 12-14th September 2005 pp 82 – 89.

Marunga A., Hoko Z., and Kaseke E. (2006), Pressure management as a leakage reduction and water demand management tool: The case of the City of Mutare, Zimbabwe. **Physics and Chemistry of the Earth**, 31: 763–770.

Meckenzie R., and Lambert A. (2004), Best Practice Performance Indicators: A Practical Approach **Water 21: Magazine of the International Water Association**, Special Series of IWA Water Loss Task Force: World Best-Practice in Water Loss Assessment, and Reduction Strategies, August: pp 43-45.

Michel Vermersch and Alex Rizzo (2008), Designing an action plan to control non-revenue water. **Water 21: Magazine of the International Water Association**, April: 39-41.

Ministry of Legal Affairs (2000), **Presidential Decree Nr. 53 on the Establishment of Sana'a Water Supply and Sanitation Local Corporation of the Secretariat of the Capital**, Official Gazette, Sana'a.

Ministry of Water and Environment (MWE) (2008), **Performance Indicators Information System (PIIS): Annual Report, 2007**. Sana'a, Yemen.

Mitchell G., Mein R., and McMahon T. (1999) **The Reuse Potential of Urban Stormwater and Wastewater**. Cooperative Research Centre for Catchment Hydrology (Industry Report, Report 99/14), Canberra.

Mutikanga, H., Sharma, S., and Vairavamoorthy, K. (2010), Assessment of apparent losses in urban water systems. **Water and Environment Journal**, (to be cited as) no. doi: 10.1111/j.1747-6593.2010.00225.x

National Audit Office (2000), **A practical guide to sampling**, publication of Statistical and Technical Team, London.

National Water Resources Authority (NWRA) (2006), **Baseline Survey for Future Impact Evaluation Document-Final Report**, NWRA -Sana'a Branch, Sana'a.

National Water Resources Authority (NWRA) (2006b), **Investigation and evaluation of private wells and water tankers in Sana'a: the physical and chemical characteristics and health conditions.** NWRA, Sana'a Branch.

National Water Resources Authority (NWRA) (2010), **The Database of Sana'a Wells.** Updated till November, 2010. NWRA, Sana'a Branch.

Núñe M., Oliver-Solà J., Rieradevall J., and Gabarrell X. (2010), Water Management in Integrated Service Systems: Accounting for Water Flows in Urban Areas. **Water Resour Manage**, 24:1583–1604

Office for Human Research Protections (2010), **International Compilation of Human Research Protections** (2010 Edition, Final Version), U.S. Department of Health and Human Services, Washington DC.

Palenchar, J., Friedman, K. and J. Heaney (2009), Hydrograph Separation of Indoor and Outdoor Billed Water Use in Florida’s Single Family Residential Sector. **Proceedings of Florida Section of AWWA Fall Conference**, November 27 - December 1, 2009, Orlando.

Puust R., Kapelan Z., Savic D., and Koppel, T. (2010), A review of methods for leakage management in pipe networks. **Urban Water Journal**, 7 (1): 25-45.

Radivojevic D., Milicevic D., and Blagojevic B. (2008), IWA Best Practice and Performance Indicators for Water utilities in Serbia- Case Study Pirot. **Factua Universitatis**, **Architecture and Civil Engineering**, 6 (1): 37 – 50.

Ranhill Utilities Berhad and the United States Agency for International Development (2008), **The Manager’s Non-Revenue Water Handbook. A Guide to Understanding Water Losses**. Malaysia/ Thailand.

Romero C., and Dukes M. (2010), **Residential Benchmarks for Minimal Landscape Water Use**. University of Florida Water Institute (the Conserve Florida Water Clearinghouse Research Agenda), Florida.

Rutsch M., Rieckermann J., Cullmann J., Ellis J.B., Vollertsen J., and Krebs P. (2008), Towards a better understanding of sewer exfiltration. **Water Research**, 42: 2385 – 2394

Sana'a Water Supply and Sanitation Local Corporation (2005, 2006, 2007, 2008, 2009), **Annual Report**, General Department of Projects and Planning, Sana'a.

Sana'a Water Supply and Sanitation Local Corporation (2009b), **A Report on Water Production and Distribution**, Production Unit, Technical Department, Sana'a.

Sana'a Water Supply and Sanitation Local Corporation (2010), **Water and Wastewater Tariff**, Commercial Department, Sana'a.

Sana'a Water Supply and Sanitation Local Corporation (2010b), **The Forth Five-Year Plan for Poverty Alleviation**, General Department of Projects and Planning, Sana'a.

Sana'a Water Supply and Sanitation Local Corporation (2010c), **Report of Performance Indicators: 2010**, Performance Indicators' Unit, Sana'a.

Singh, R., Maheshwari, B. L., and Malano, H. M., (2009) Developing a conceptual model for water accounting in peri-urban catchments. **The 18th World IMACS Congress and MODSIM 09, International Congress on Modeling and Simulation**, July 13–17, 2009, Cairns, Australia, pp 7- 14.

Steinar K. (2007), Learning the Craft of Interviewing. In: Flick, Uwe (Ed), **Doing Interviews**. (pp.137-141), U.K., SAGE Publications.

Sufian T., Altowaie H., Knies G., Trieb F., and Kern J. (2006), **Water for Sana'a and Taiz'z from Solar Desalination at the Red Sea; Proposal for saving Sana'a and Taiz'z and serving all Yemen**, Trans-Mediterranean Renewable Energy Cooperation (TREC), Sana'a/Hamburg.

The International Bank for Reconstruction and Development (The World Bank) (2007), **Making the Most of Scarcity; Accountability for Better Water Management in the Middle East and North Africa**, Washington, DC.

The International Bank for Reconstruction and Development (The World Bank), Cities Alliance, and Capital Secretariat of Sana'a.(2009), **Sana'a A City Development Strategy**. A report of strategic planning for Ministry of planning and development, Washington DC.

The International Fund for Agricultural Development (IFAD) (2010), Calculating the Sample Size. Retrieved November 29, 2000, from **http://www.ifad.org/gender/tools/hfs/anthropometry/ant_3.htm**

The Stimson Center (2010), **Fresh Water Futures: Imagining Responses to Demand Growth, Climate Change, and the Politics of Water Resource Management by 2040**. A report of the future of global fresh water resources and the politics of water resource management, National Intelligence Council and the US State Department, Washington DC.

Thornton J, and Lambert A. (2005), Progress in practical prediction of pressure: leakage, pressure: burst frequency and pressure: consumption relationships.

Proceedings of IWA Specialized Conference 'Leakage 2005', Halifax, Nova Scotia, Canada 12-14th September 2005 p347-358

Thornton J., Sturm R., and Kunkel G. (2008), **Water Loss Control**, (2nd ed.). USA: McGraw-Hill Companies Publishers.

United Nations Development Program (2009), **Arab Human Development Report: Challenges to Human Security in the Arab Countries**. Regional Bureau for Arab States, New York.

Water and Environment Center (WEC) (2010) **Unaccounted For Water Training Program: Minimum Night Flow Analysis in Al-Akama Area, 2nd Zone**. Unpublished Report, WEC-Sana'a University.

Water and Environment Center (WEC) (2010). Personal Communication, WEC-Sana'a University.

Western Australian General Practice Network (2008), **Toolkit – Staff surveys of awareness and satisfaction with the Division's IM processes and systems**. Divisions of General Practice, Information Management Maturity Framework, Bentley, Western Australia.

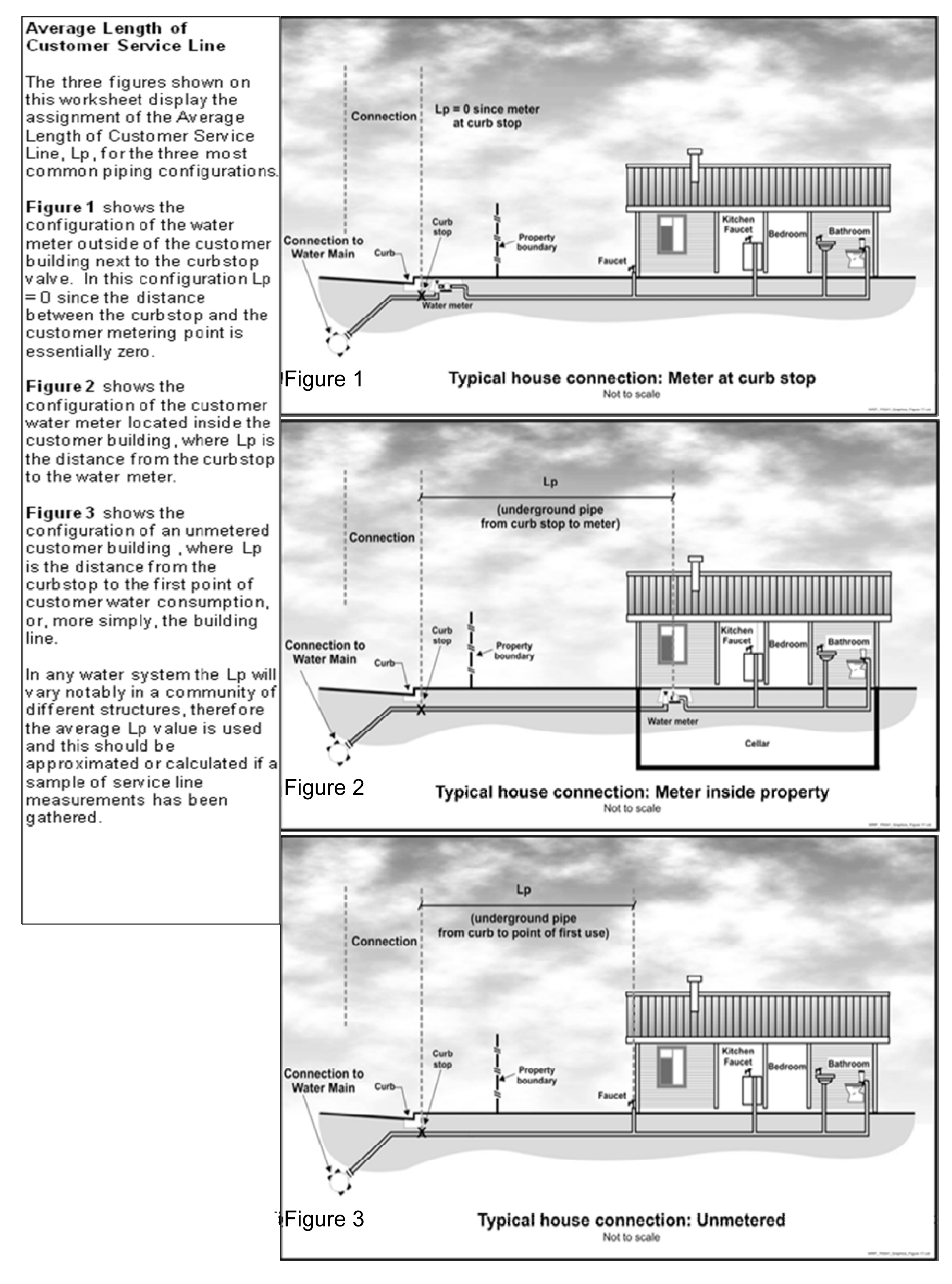
Winarni W. (2009), Infrastructure Leakage Index (ILI) as Water Losses Indicator. **Civil Engineering Dimension**, 11 (2): 126-134

World Bank Institute, 2009. Free Water Balance Software V.3.00

Zeug G., and Eckert S.(2010), Population Growth and Its Expression in Spatial Built-up Patterns: The Sana'a, Yemen Case Study. **Remote Sensing**, 2: 1014-1034

Appendices

Appendix 1: Average Length of Customer service Line (Lp)



Appendix1: Average Length of Customer service Line Lp for the purpose of calculating the Infrastructure Leakage Index (ILI) Lp: the total length of private pipe or property boundary to customer meter. Source AWWA, 2009

Appendix 2: List of interviewees

Date	Interviewee	Position	Topic
6/10/2010	Mr. Adel Al-Haddad	Deputy Minister-MWE	current NRW projects - JICA & GTZ, Authorization
9/10/2010	Mr. Grellium	GTZ Component 2: Team Leader,	potential contribution of the research, status quo of NRW project
	Mr. Shwagfeh	GTZ Component 2: Senior Consultant	
	Mr. Thomas	Dorsch Consultant-O&M Project-Team Leader	
6/10/2010	Mr. Ali Zabarah	IT Department Manager	NRW-data cycle and availability
6/10/2010	Mr. Ali Jadel	Sanaa Water Project, Team Leader	zoning of new projects
7/10/2010	Mr. Saleh Abdulwadood	Technical Department Manager	physical loss: level, causes, solutions
			possibility of conducting MNF analysis
23/10/2010			hierarchy of technical Department & suggested NRW Unit, its stakeholders
7/10/2010	Dr. Fadhl Al-Nozaily	Scientific Consultant of the utility	NRW assessment, MNF analysis
8/10/2010	Dr. Mansor Hydraa	Prof, Water and Environment Center	the suggested approach- NRW assessment, previous trials of MNF analysis
9/10/2010	Mr. Mohammad Amin,	DCMMS- Complaints- Telephonist	leakages complaints and procuress of repairs
	Mr. Ibrahim Amer		
9/10/2010	Mr. Jameel Shehatal	Dorsch Consultant-O&M Project-Senior technician	NRW reduction project- OMs project and subprojects
9/10/2010	Mr. Abdulhack Al-sharafi	GIS unit - head	Available GIS data
10/10/2010	Mr. Nabeel Al-Shagdari	Statistical Department Manager	Annual reports , the utility five-year plan
10/10/2010	Mr. Mohammed Bawragy	Water laboratory- head	complaints of water pollution caused by leakages
10/10/2010	Mr. Ahmad Othman	Water laboratory- Manager	complaints of water pollution caused by leakages
11/10/2010	Mr. Ibrahim Jelhem	water production unit- technician	production data, meters maintenance

Date	Interviewee	Position	Topic
12/10/2010	Eng. Adanan Al-Kebsi	VAG project- engineer	pressure management project
15/10/2010	Mr. Abdulfatah Al Hadi	complaints and maintenance unit-manager	DCMMS project
15/10/2010	Eng. Faisal Al-Afeef	Distribution unit- manager	distribution pattern, NRW suggested unit
16/10/2010	Mr. Shawgi Malek	Meters workshop-technician	customer meters accuracy, meters complaints
17/10/2010	Mrs.	GTZ-HRD- SWSSLC	NRW training program
18/10/2010	Eng. Mohammad Al-komaim	Technical department- engineer	Zoning trials and difficulties
19/10/2011	Mr. Qasem Ameen	Commercial Department Manager	Apparent losses, billing and collection policies, meter readers errors
23/10/2012	Mr. Abdullah Qarmash	Distribution unit- technician	operating pressure
23/10/2013	Mr. Ahmad Al-Rajawy	Technical department- secretary	NRW data
24/10/2014	Mr. Mohammed Al Qodaimi	Prodution unit - head of unit	production meters inaccuracies
24/10/2015	Mr. Adnan Al-Sanhani	Computer department- engineer	consumption data analysis
26/10/2010	Mr. Abdulwahab Al-Fosail	The fifth administrative zone-Manager	zoning, meter reading loyalty, NRW assessment
25/10/2010	Eng. Abdallah Al- Motaa	Wastewater projects- team leader	wastewater coverage in 2008
25/10/2010	Mr. Husain Al-Sharrafi	Wastewater projects/ Specialist	wastewater coverage
26/10/2010 7/11/2010	Mr. Taha Al-Saiaghi	Deputy Manager	unauthorized Consumption-Legal and political constraints
28/10/2010	Mr. Abdulkareem Nokhra	Commercial Department / Specialist	meter reading errors
7/11/2010			meter readers' job stability

Appendix 3

Current Non-Revenue Water Related Policies in Sana'a Water Utility

AL-Washali T.

November, 2010

Table of Contents

1. Current Non-Revenue Water Assessment in Sana'a Water Utility

Sana'a water utility determines non revenue water by subtracting the billed water from the produced water. Then the result is reduced by what is so called "counted losses" to provide what the utility defines as "real losses".

Count losses in NRW assessment in Sana'a water utility include: (1) estimated volumes of water of repaired leakages; (2) water for pipe washing and operational purposes;(3) water of firefighting; (4) estimated water of stopped meters' consumption; (5) consumption of flat rate customers; (6) the utility buildings consumption as well as wells guards' consumption; and (7) exemptions, or water tankers to special institutions, and some notable people.

Sana'a water utility neither adjusts the production water volume for under-registration nor does it adjust the billing records for time lag. Even though the utility estimates under-registration of production well's meters at 5-10%, no adjustment for this under-registration is adopted when calculating the system input volume for the purpose of NRW determination. Besides, some of the production data are not measured but estimated. For example, there is no access to some wells' meters due to corrupting practices; in consequence, the production of the subject well is estimated.

1.1. NRW components breakdown and PIs

The only reported way of defining the components of NRW in Sana'a water utility is through assuming 50% for real losses and 50% for apparent losses as stated in the annual production and distribution report (SWSLC, 2009b). Nonetheless, the guesstimation range differs from department to department. While the commercial department weights the apparent losses higher value, some staff of the technical units believes that real losses are likely to be higher. However, the dominant guesstimation of NRW components is around 60% for apparent losses and 40% for real losses.

On the other hand, the only performance indicator used in Sana'a water utility for NRW is losses volume as % out of system input volume.

2. Current Non- Revenue Water Related Policies

2.1. Real losses

2.1.1. Network conditions

Sana'a water network is very old. Since its start in the 1960s, the network expanded randomly with no master plan nor adequate attention was paid to documenting the network drawings. The result is lack of knowledge about the network or locations of its components (e.g. valves). In sequence, the administrative zones are defined geographically with interlocked networks accompanied with shared water feeding sources.

Due to dwindling of water resources in the city and intermittent supply in the utility, operational fatigue in the network accelerate the leakages occurrence and thus significant increasing of level of leakages was recorded.

2.1.2. Policy in practice for production metering

- Neither regular maintenance nor replacement policy is adopted for production meters.
- There is only one master meter left working for the west wells' field. Records of this meter indicate that 7% of the field production is losses in the way from the well to the reservoir; most of this amount is estimated to be used in looting the irrigated lands at the wells' areas.

2.1.3. Reduction Trials

Zoning

Many trials have been made to reduce leakages through zoning, but were encountered with incompleteness of knowledge about locations of valves, and faced by multi-feeding source of water for each zone or area. Another difficulty encountered is that water distribution pattern is for different defined areas than the suggested zoning areas. So far, no trial has succeeded.

DCMMS system

Data Center Maintenance and Management Software is a system for customer complaints and reported leakages' maintenance. The system has a "hot line" through which customers' complaints are recorded systematically and the time period of repairing the leakages is then counted and documented with all data involved. The system started recently in 2009 and the average recorded repairing time is 123.7 hours for 2354 leakages in 2009.

Pressure management

There is a recent project for pressure management for hilly area in Nokom in the first zone. The project was implemented by VAG Armaturen in a public private partnership project. The project aimed at reducing pressure by installing Pressure Reducers Valves(PRV); however, the project has failed because of intermittent supply for both water and electricity. Even though the project is still recent (2008-2009), it is already stopped.

2.2. Apparent losses

2.2.1. Customer confidence

No meter replacement policy had been adopted by Sana'a water utility for decades till the 2000s when the under-registration rate could not be ignored any more. When the utility decided to replace meters, the policy was accompanied by raising the tariffs. The customer, who used to pay certain range of bill price for years, was surprised with significant jump in the bill price due to the new dry meter that measure water and air, whatever amount of air is, and the new high tariff as well. Since then, the customer's confidence started to decline significantly.

2.2.2. Water allocation and competition

Water is allocated at different quantities among customers because of (1) increasing water scarcity; (2) water production costs and difficulties; (3) and the uncertainty of how much/ how water in the network is being diverted within the distribution areas. Whereas some customers receive water few hours a week, some receive the service 3-7 days a week. A lot of water insufficiency complaints have been recorded and competition among customers in many areas to get the water by means of pumps during water provision times was recognized by the utility. Most of these pumps were installed in a way that meters do not measure the flow. In other words, pumps were installed with illegal bypass connections.

2.2.3. Employees' loyalty and job stability

Employees at low or "base" management levels such as technicians and meter readers are the most affected segment of the dwindling economy of the country. Putting this in mind, many technicians and meter readers in Sana'a water utility enjoy no job stability, social insurance, or "as the others" incentives. The result is corrupting practices; For example, 30% of tampered meters which are received in the utility's meter workshop are caused by professional technicians of the utility.

2.2.4. Current policies

Policy in practice for meter readers

Customers' meters are read monthly by readers whose duties are recording the consumption, bills delivering, and following up unpaid bills. Each reader is responsible for 800 customers. The task of recording the consumption should be accomplished in duration of 10 days; from 26^{th} of the month to 5^{th} of the following month. Besides, when the customers complain about potential meter over-registration, the reader should be in charge of the process of removing, checking, and re-installing the meter.

Policy in practice for getting customers pay

Those customers who do not pay the bill for several months are disconnected from the service. Those who eventually pay the water bill are reconnected. To ensure that disconnected customers do not use water illegally, re-investigations are made. Nevertheless, not all the disconnected customers are reinvestigated or reconnected; only part of them. Table 1 and Figure 1 shows the rate of disconnected and reconnected water connections for customers that haven't paid water bills in 2009.

Policy in practice for revenue generating

Sana'a water utility, SWSLC, has analyzed the volume of water consumption for its customers in 2009. The results revealed that more than 50% of its customers consume not more than 10 M^3 per month as shown in Figure 2 With an average number of people for the connection as 12 person per service connection, Sana'a water utility believe that customers of the 50% of consumption with less than 10 M^3 per month could not be true unless most of those customers have bypass connections. The reactive policy that Sana'a water utility conducted is to make 10 M^3 as a minimum limit for consumption per month for each customer. This policy is new and yet have neither been known by customers of Sana'a water utility nor by Ministry of Water and Environment.

Table.1

Number of Disconnected - Re-connected and Detected Illegal Connections

Source of data: SWSLC, 2005-2009

Year	Nr. Disconnected connections	Nr. Re-connected connections	Difference	Nr. Detected illegal connections
2005	21928	3248	18680	793
2006	13646	2435	11211	657
2007	15901	3173	12728	528
2008	18192	2275	15917	438
2009	22559	2393	20166	568
Ave	18445	2705	15740	597

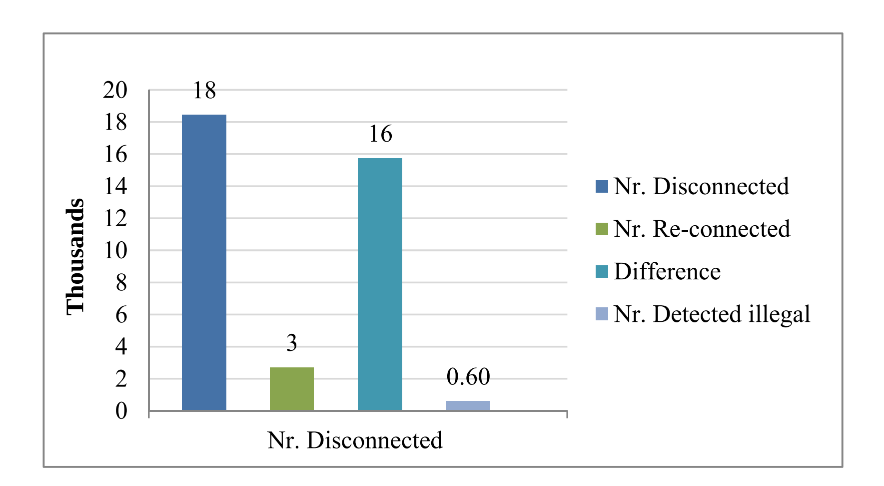


Figure.1: Average number of disconnected - re-connected and detected illegal connections in Sana'a water utility for the years 2005-2009

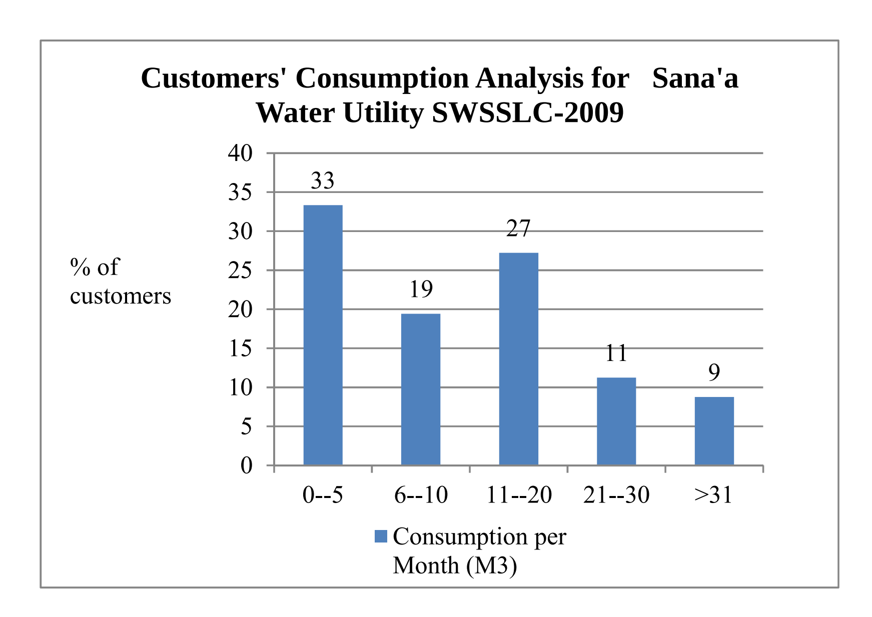


Figure.2: Customers' Consumption Analysis for Sana'a Water Utility-2009

2.2.5. Reduction activities

- Sana'a water utility conducts several, but not enough, investigation campaigns for stopped meters or customers with too low consumption. Then estimated consumptions are determined based on historical data, and bills are distributed with the estimated consumption.
- Some years ago, there were a lot of exemptions from paying water bills for the employees of the utility and some customers. The policy now is replaced by providing incentives in term of money rather than exemption of unlimited volume of water.
- Training for meter readers has recently started within the operation and maintenance program sponsored by GTZ trying to reduce meter reading errors and associated corrupting practices.
- Sana'a water utility has suited many customers for illegal water use. Sana'a water utility disregarded this policy for the following reasons:
  - There is lack of clear lows and legislations with regard to illegal water use
  - Lack of court ruling enforcement
- There is no official Sharia fatwa regarding illegal water use. Although Mofte of the Republic of Yemen has a clear position against the illegal water use, yet, no official fatwa has been obtained by Sana'a water utility.

Appendix 4A: Social questionnaire for defining reasons of illegal water use in Sana'a water distribution system-Arabic Version

بسم الله الرحمن الرحيم

استبيان ورأى المجتمع فى أسباب الفاقد الادارى وتحديد مستوى خدمة المياه ضمن رسالة ماجستير
فى إدارة فواقد المياه فى نظام امداد مياه مدينة صنعاء

الأخ الفاضل، تحية طيبة وبعد

أقدم بين يديك هذه الاستبانة كأداة لدراسة إدارة فواقد المياه في نظام امداد مياه مدينة صنعاء، أرجو منك شاكراً التعاون بالإجابة على فقراتها، علماً بان المعلومات المستفادة منها لن تستخدم الا لأغراض البحث العلمي وان المطلوب هو تقييم إدارة فواقد المياه بالمؤسسة ، وسيكون لإجاباتك الموضوعية عظيم الأثر في إثراء هذا البحث. ..شاكراً لك تعاونك وموضوعيتك الباحث

أولاً : بيانات عامة

التاريخ					المنطقة		مدة الاشتراك في الخدمة				
الجنس		ذكر		أنثى	المستوى التعليمي		نوع المسكن		منزل		شقة
العمر					المهنة				فيلا		غير ذلك

ثانياً: مستوى خدمة المياه المقدمة من المؤسسة:

سأقوم بذكر الخدمات التي تقدمها المؤسسة وارجوا إبداء رأيك فيما اذا كانت الخدمة المذكورة مرضية لك او غير مرضية أو ليس لديك فكرة عنها:

م/1	نوع الخدمة	مرضي	غير مرضي	لا أدري	إذا كان غير مرضي فما السبب
1	كمية المياه المقدمة من المؤسسة (كفايتها)				
2	نوعية المياه المقدمة من المؤسسة				
3	انتظام مواعيد إمداد خدمة المياه				
4	العدالة في توزيع المياه بين المناطق السكنية				
5	طريقة تعامل موظفي المؤسسة				
6	خدمات الصيانة				
7	خدمات الشكاوى (ت: 171)				
8	أداء موظفي قراءة العدادات وتوزيع الفواتير				
9	سعر المياه (تعرفة المياه)				

2	الأداء العام للمؤسسة في ظل الوضع المائي لحوض صنعاء				

ثالثا: جوانب الفاقد الاداري:

م	السؤال	كبيرة جدا	كبيرة	قليلة	لا يوجد	لا أدري
3	كم تتوقع كمية سرقات المياه في شبكة المؤسسة؟					

م	السؤال	لا	نعم	عددها تقريبا	أتحفظ
4	هل تعلم عن سرقات مياه تحصل في حيّك او الشارع الذي تعيش فيه؟				

5. برأيك ، ما هو الحل للحد من سرقات المياه؟

....
....
....
....

6. برأيك ما سبب سرقات المياه في الشبكة؟ (يتم وضع √ أمام السبب)

م/6	سبب التوصيلات الغير قانونية	√P10
1	ضعف إجراءات الضبط والمتابعة من المؤسسة	
2	قلة توفر المياه في الشبكة والتنافس عليها	
3	سعر فاتورة المياه مرتفع	
4	الإعتقاد بأن خدمة المياه ينبغي أن تقدم مجاناً	
5	تعقيد إجراءات الحصول على اشتراك في خدمة المؤسسة	
6	يحق للمواطن استخدام المال العام	
7	الفقر	
8	غير ذلك :	

م	السؤال	نعم	لا	البعض	لا أدري
7	في حال صدور فتوى شرعية بحرمة سرقات المياه برأيك هل سيتوقف المخالفين عن هذه السرقات؟				P11

رابعاً: رد فعل المشترك لاجراءات إدارة الفاقد

م	السؤال	نعم	لا	لماذا
8	إذا علمت أن كمية التسريبات في شبكة المياه كبيرة و اصلاحها يحتاج الى رفع سعر المياه: فهل توافق على رفع سعر المياه حفاظا على المياه المهدرة ؟			
9	إذا كان يتم احتساب قيمة 10 وحدات كحد أدنى في فاتورة المياه، وكانت كمية استهلاكك للمياه أقل من ذلك : فهل ستحاول زيادة استهلاكك لاستغلال الكمية التي تدفع قيمتها ؟			P13

شكرا جزيلاً،،

Appendix 4B: Social questionnaire for defining reasons of illegal water use in Sana'a water distribution system-Translation of questions

Non-Revenue Water Management in Sana'a Water Distribution system

Social Questionnaire for Defining Causes of Illegal Water Use

1. General Information

Date					Zone		Duration of service subscription				
Gender	Mal e		Female		Qualification		Type of House	House		Apt	
Age					Job			Villa		Other	

2. Customers level of satisfaction for water service

1/No	Question	Satisfying	Not Satisfying	Why not
1	Quantity of water delivered			
2	Quality of water			
3	Water service schedule's commitment			
4	Fairness of service distribution along the city			
5	The utility's employees Dealing			
6	Maintenance services			
7	Compliances' services			
8	Meter reading and billing practices			
9	Water tariff			
2	General performance of the utility considering the situation of Sana'a basin			

3.Causes and prevalence of apparent losses

No	Question	Very high	High	low	I don't Know
3	Illegal water use in the utility network is..?				

No	Question	No	Yes	how many	No comment
4	Do you know illegal water use in your neighborhood or street?				

5. In your opinion, what is the solution for limiting illegal use?

……
……
……
……
……
……
……………………………………………

Please mark the cause of Illegal Use in the utility's network:

6/no	Question	✓
1	Water tariff	
2	Low water availability in the network	
3	The belief that water service should be free of charge	
4	Weak monitoring and inspection procedures	
5	Complicated procedures of service subscription in the utility	
6		
7		
8		

No	Question	Yes	No	Some	I don't Know
7	Religious Fatwa that illegal water use is prohibited would be an effective tool for limiting illegal use?				

4. Customer Reaction for the utility policies

No	Question	Yes	No	Why
8	If you know that leakages in the network are high and its rehabilitation needs rising water tariff, If so, do you accept rising water tariff to save the wasted water?			
9	Assuming that 10 units are the minimum limit of consumption per month and they are counted in the bill, and you usually consume less than 10 units per month, Would you try to consume the whole 10 units that you pay for?			

End...Thank you..

Appendix 5A: Illegal water users' questionnaire for defining reasons of illegal water use in Sana'a water distribution system-Arabic Version

بسم الله الرحمن الرحيم

أسئلة استبيان المقابلة لمالكى التوصيلات الغير رسمية ضمن ماجستير إدارة فواقد المياه فى نظام امداد مياه مدينة صنعاء

أولاً : بيانات عامة

التاريخ					المنطقة		الدخل الشهري				
الجنس		ذكر		أنثى	المستوى التعليمي لكبير الأسرة		نوع المسكن		منزل		شقة
العمر					المهنة				فيلا		غير ذلك

ثانياً: أسباب استخدام المياه بدون إذن من المؤسسة:

م	السؤال	نعم	لا	لا أدريِ
1	هل لديك عداد بجانب توصيلة المياه الحالية؟			———
2	ما هو السبب الدافع لاستخدامك التوصيلة الحالية للمياه؟ أ: سعر المياه غير ملائم للخدمة ب: كمية المياه غير كافية ج: ليس هناك عدالة في التوزيع د: الفقر وعدم القدرة على دفع قيمة فاتورة المياه هـ: يحق لاي شخص استخدام المال العام و: غير ذلك			
3	منذ عام كم تسخدم المياه عن طريق التوصيلة الحالية؟			
4	من قام باعمال سباكة التوصيلة الحالية؟	موظف في المؤسسة	صاحب المنزل	سباك من السوق

م	السؤال	نعم- كم مرة	لا	لا أدريِ
5	هل سبق و نفذت المؤسسة حملات تفتيش لمثل هذه التوصيلات في حيك او شارعك؟			

شكرا جزيلاً،،

Appendix 5B: Illegal water users' questionnaire for defining reasons of illegal water use in Sana'a water distribution system-Translation of questions

Non-Revenue Water Management in Sana'a Water Distribution system

Questions of Interviews for Illegal Water Users

1.General Information

Date				Zone		Monthly income				
Gender	Male		Female		Qualification of person in charge		Type of House	House		Apt	
Age				Job			Villa		Other	

2. Reasons for illegal use

No	Question	Yes	No
1	Do you have water meter besides your current water connection?		
2	What is the reason for using water through your current connection? …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… …………………………………………………………………………… ..		
3	How long have you been using water through the current water connection?		
4	Who made the plumping work for your illegal connection?		
No	**Question**	**Yes/ how often**	**No**
5	Have the water utility made inspection campaign to your street?		

THANK YOU

Appendix 6: Estimating Data Handling Errors in SWSLC by Auditors from the headquarters to the Fifth Zone and Statistical Analysis

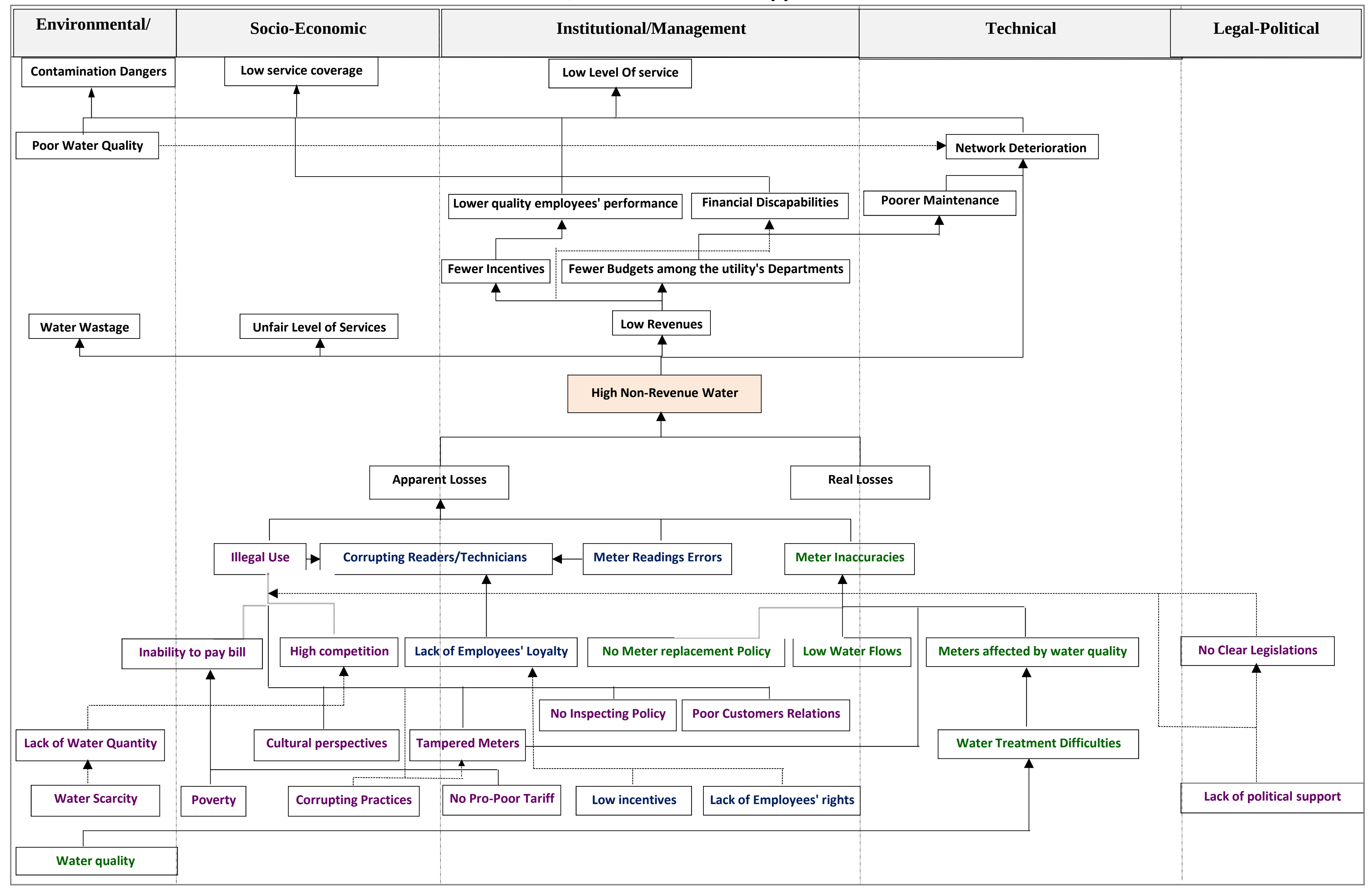
No	Zone Nr. (1)	Square code (2)	Number of customers (3)	Consumption of May 2010 (4)	Consumption of June 2010; By Audits (5)	Difference of Consumption (6)	Difference per customer (7)	Average of column7 (8)	Variance (8) with (7)	statistical difference of consumption = (8) * (3)	Reading Errors (10-6)	Type of Errors
1	5	192	1,118	15482	39228	23,746	21.240	-0.239154	230.671	-267	-24,013	losses
2	5	191	1,101	16555	26348	9,793	8.895	-0.239154	41.713	-263	-10,056	losses
3	5	201	823	13576	13767	191	0.232	-0.239154	0.111	-197		
4	5	271	1,110	16217	16401	184	0.166	-0.239154	0.082	-265		
5	5	306	25	2168	2275	107	4.280	-0.239154	10.211	-6	-113	losses
6	5	273	1,080	10650	10650	0	0.000	-0.239154	0.029	-258		
7	5	281	15	177	142	-35	-2.333	-0.239154	2.193	-4		
8	5	251	1,011	13922	13753	-169	-0.167	-0.239154	0.003	-242		
9	5	272	1,330	21409	21185	-224	-0.168	-0.239154	0.003	-318		
10	5	91	1,019	14141	13901	-240	-0.236	-0.239154	0.000	-244		
11	5	215	459	8705	8356	-349	-0.760	-0.239154	0.136	-110		
12	5	93	348	4288	3938	-350	-1.006	-0.239154	0.294	-83		
13	5	94	191	2506	2015	-491	-2.571	-0.239154	2.718	-46		
14	5	175	696	7769	7246	-523	-0.751	-0.239154	0.131	-166		
15	5	213	1,356	20233	19630	-603	-0.445	-0.239154	0.021	-324		
16	5	253	689	12685	12071	-614	-0.891	-0.239154	0.213	-165		
17	5	171	865	10884	10188	-696	-0.805	-0.239154	0.160	-207		
18	5	211	985	15404	14577	-827	-0.840	-0.239154	0.180	-236		
19	5	173	868	10402	9438	-964	-1.111	-0.239154	0.380	-208		
20	5	252	706	9405	8333	-1,072	-1.518	-0.239154	0.818	-169		
21	5	172	1,065	15175	13722	-1,453	-1.364	-0.239154	0.633	-255		
22	5	92	1,351	22434	20645	-1,789	-1.324	-0.239154	0.589	-323		
23	5	174	943	16732	14887	-1,845	-1.957	-0.239154	1.475	-226		
24	5	212	1,290	13055	10640	-2,415	-1.872	-0.239154	1.333	-309		
25	5	305	202	20820	17801	-3,019	-14.946	-0.239154	108.139	-48	2,971	Profits
26	5	214	1,420	19674	16421	-3,253	-2.291	-0.239154	2.105	-340		
27	5	202	978	15294	11466	-3,828	-3.914	-0.239154	6.753	-234	3,594	Profits
	Total		23,044	349762	359024							
	Total		**23,044**	**349762**	**359024**							
Data were statistically analyzed using rank-test and variance comparison												

Estimating Volume of Data Handling Errors and Corrupting Practices in the Fifth Zone-SWSLC by Statistical Analysis for Meter Readings of May-June, 2010*		
Errors	Volume (M^3)	Errors of Consumption (%)
Losses	-34183	-9.6
Profits	6565	1.9
Absolute Total	40747	11.5
Net	-27618	-7.79
*For Nr. of customers = 23044; Average consumption = 354393 M^3/month		

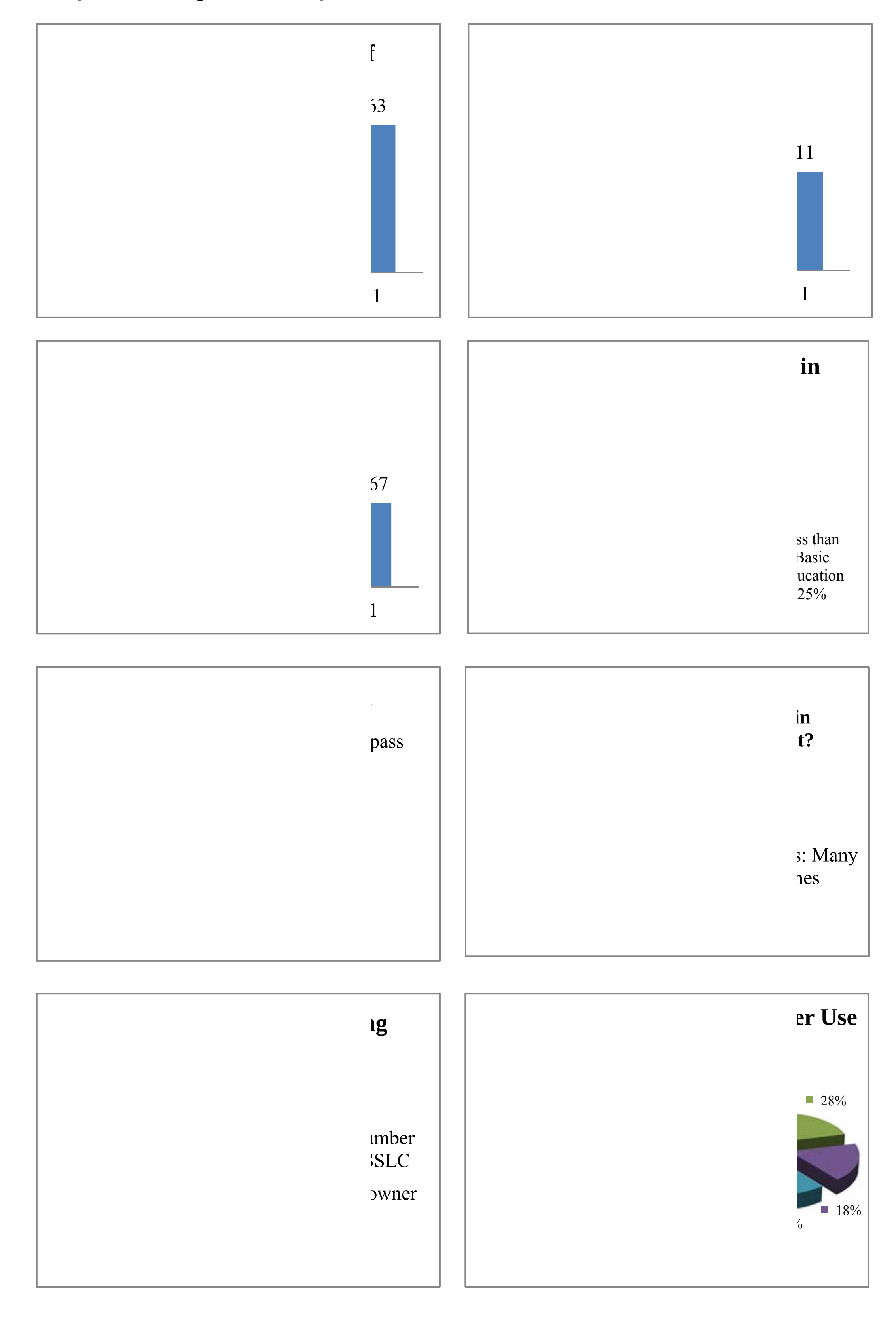
Calculating the Weighted Average of Data Handling Errors for All the Administrative Zones in SWSLC		
Administrative Zone	Nr. of customers (with meters)	Meters reading errors of metered consumption (%)
5th	23044.0	-7.79
1,2,3,4*	63175.0	-4.95
Total	86219.0	
Weighted Average		-5.71
* Data handling errors for these zones are estimated by SWSLC at -3% of system input volume which makes -4.95% of the consumption in 2009		

Errors of Data Handling and Corrupting Practices of Meter Readings in SWSLC		
unit	Out of Metered Consumption	Out of System input volume
%	**-5.71**	**-3.46**
M^3/day*	2112.92	
*For 2009, Consumption = 37003.84 M3/day; System input volume = 61069 M3/day		

Appendix 7: Problem Analysis for Apparent losses in Sana'a Water Distribution System
Root Causes are at the Bottom; Effects are at the Upper Part



Appendix 8: Sample characteristics and results of four recovered samples of Illegal users' questionnaire



Appendix 9A: NRW awareness questionnaire for measuring NRW awareness in SWSLC- Arabic Version

بسم الله الرحمن الرحيم

الموضوع :- استمارة استبيان لتقييم أسباب فاقد المياه، وكذلك وعي، و أولويات المؤسسة في قضايا الفاقد

دراسة لأراء عينة من مدراء إدارات ، رؤساء أقسام، مهندسين، ومختصين الإدارات الفنية، التجارية، والتشغيلية بالمؤسسة المحلية للمياه والصرف الصحي- الأمانة

الأخوة الأفاضل: مدراء الادارات ، رؤساء الأقسام ، مهندسين ، مختصين..   المحترمون

تحية طيبة وبعد

أقدم بين أيديكم هذه الاستبانة كأداة لدراسة إدارة فواقد المياه في نظام امداد مياه مدينة صنعاء، أرجو منكم شاكراً أن تتفضلوا بالإجابة على فقراتها , علماً بان المعلومات المستفادة منها لن تستخدم الا لأغراض البحث العلمي وان المطلوب هو تقييم أولويات الوضع الحالي و المستقبلي لادارة الفاقد بالمؤسسة ، وليس بالضرورة اتفاقكم مع الأراء المطروحة داخل الاستبيان،

وسيكون لإجاباتكم الموضوعية عظيم الأثر في إثراء هذا البحث.

وتقبلوا فائق الاحترام والتقدير

الباحث

برنامج الإدارة المتكاملة للموارد المائية
الجامعة الأردنية/جامعة كولون

البيانات الشخصية

المؤهل : (   ) ثانوية عامة (   ) جامعي (   ) دراسات عليا (   ) غير ذلك

التخصص: ....

العمر (اختياري)...

الجنس: ....

الإدارة: ....

المنصب (مدير إدارة ، رئيس قسم ، مهندس، مختص ،....): ....

سنوات الخبرة: ....

إستبيـــــــان

ملاحظة هامّة: الرجاء التحديد على مربع "محايد" في حالة عدم الإلمام بنقطة معيّنة شاكرين للموضوعية

المحور الأول

م	العبـــــــــــــــــــــــــــــارة	موافق بشدة	موافق	محايد	غير موافق	غير موافق بشدة
1	تحسب كمية فواقد المياه بناء على كمية المياه المنتجة والمباعة	ماهية	P2-1-4			
2	فواقد المياه تزيد من كمية الطلب على المياه	بيئة	P2-1-1			
3	تؤثر التسريبات على نوعية مياه الشرب المقدمة للمشتركين	صحة	P2-1-5			
4	يؤثر الفاقد على مستوى خدمة المياه المقدمة للمشترك	مؤسسي	P2-4-1			
5	تعيق زيادة فاقد المياه المؤسسة على توسيع إطار خدمة المياه	مؤسسي	P2-1-3			
6	تسبب فواقد المياه صعوبة في عملية تشغيل الشبكة فنيا	تشغيلي	P2-1-2			
7	زيادة فواقد المياه يتطلب زيادة تكلفة صيانة الشبكة	مالي	P2-3-4			
8	يسبب زيادة كمية الفاقد زيادة تعرفة المياه	مالي	P2-3-2			

المحور الثاني

9	توجد طرق علمية يمكن للمؤسسة ان تسخدمها لتحديد كميات الفاقد الفيزيائي والفاقد الإداري		P2-2-1			
10	يمكن التعبير عن مستوى فواقد المياه بمؤشرات عديده غير النسبة المئوية % من كمية المياه المنتجة		P2-2-3			
11	موازنة المياه (ميزانية المياه– water balance) او قياسات كمية المياه في الانابيب أثناء الليل (minimum night flow) هي طرق لحساب كمية الفواقد		P2-2-2			
12	يستخدم دليل تسريبات الشبكة (Infrastructure Leakage Index)، كمؤشر أداء للفواقد الفيزياية لمؤسسات المياه		P2-2-4			

المحور الثالث

م	العبـــــــــــــــــــــــارة	موافق بشدة	موافق	محايد	غير موافق	غير موافق بشدة
13	إدارة فواقد المياه ليست مهمة الإدارة الفنية والتجارية فقط		P2-3-7			
14	يؤثر تصميم وتنفيذ شبكات المياه على ادارة فواقد المياه	مشاريع	P2-3-6			
15	الاستقرار الوظيفي لموظفي الادارات الفنية والتجارية يؤثر على كمية فواقد المياه	إداري	P2-3-8			
16	كفاءة وولاء قرّاء العدادت من العناصر المؤثرة على كمية الفواقد	تدريب	P2-3-1			
17	ضعف علاقات المشتركين بالمؤسسة يزيد من فاقد المياه	علاقات	P2-3-9			
18	تؤثر كمية المياه الموزعة و جداول التوزيع على كمية الفواقد	توزيع	P2-3-5			

إنتهى..شكرا جزيلا

Appendix 9B: NRW awareness questionnaire for measuring NRW awareness in SWSLC- Translation of questions

Non Revenue Water Management in Sana'a Water Distribution System

Questionnaire designed to measure awareness level of Non-Revenue Water Management for employees of relevant departments in Sana'a water utility

Personal data

Qualification: High school ( ) Bachelor ( ) Master ( ) Other( )

Specialization:……………………………………………………………….......

Age (optional):……………………………………………………………………

Gender:………………………………………………………………………………

Department:…………………………………………………………………………..

Position:………………………………………………………………………...........

Years of experience:………………………………………………………………

Note: please mark at "Neutral" in case there is no background about a certain point

Part 1:

No	Phrase	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1	Water losses is calculated from volume of produced water and the billed water					
2	Water losses increase the demand of water					
3	Leakages influences the quality of water in the network					
4	Water loss affects level of water service					
5	Water losses restricts the utility from expanding its service coverage					
6	Water loss management has a direct impact on the technical situation of the network					
7	Water loss requires more budget for network maintenance					
8	Water loss influence the tariff price					

Part 2:

9	There are methods utility can use to estimate the amount of commercial and physical losses					
10	Percentage of produced water is not the only indicator for water losses					
11	Water Balance or Minimum Night Flow analysis could be used for calculating water losses					
12	Infrastructure leakage Index is a performance indicator for the physical losses in the distribution system					

Part 3:

No	Phrase	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
13	Water loss management is not a task of the technical and commercial departments only					
14	Studies and designs of networks facilitate water loss management					
15	Technicians and meter readers' incentives and job stability is related to water loss					
16	Meters readers qualification and loyalty is an important element of the utility's revenues					
17	Customer relations' activities influences water loss					
18	Water distribution durations and schedules influence water losses					

Thank You

Annex 1: DECLARATION

Name Taha AL-Washali

Matr. No.:

I, Taha AL-Washali, declare hereby on oath that this Master Thesis in hand has been made independently and without the help of any other than acknowledged.

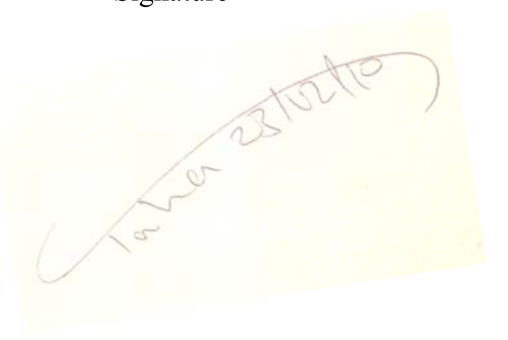
The thoughts taken directly or indirectly from external sources are made recognisable as such. This thesis was not presented to any other examination authority either in the same or similar form and till now it has not been published.

Cologne, Signature

December 23, 2010

I do further agree to a later publication of this Master Thesis, may it be in parts or entirely within the ITT publications or within the scope of the ITT‟s public relations.

Signature



إدارة فواقد المياه في نظام إمداد مياه مدينة صنعاء

إعداد
طه محمد الوشلي

المشرف
الأستاذ الدكتور عباس العمري

المشرف المشارك
الأستاذ الدكتور لارس ريبّى

ملخـــــص

تتناول هذه الدراسة إدارة فواقد المياه في نظام امداد مدينة صنعاء بهدف تقدير كمية الفواقد بانواعها ومن ثم دراسة سياسات الفاقد الإدارية التي تتبناها مؤسسة المياه والصرف الصحي بأمانة العاصمة صنعاء. علاوة على ذلك ، تطرقت الرسالة الى قياس وعي موظفيّ المؤسسة بالقضايا المتعلقة بإدارة الفاقد.

فيما يخص تقدير كمية الفواقد ، قامت الدراسة بعرض لامكانية تطبيق المناهج والطرق العلمية المتوفرة على الوضع الحالي لشبكة المياه بالمؤسسة. بعد ذلك قامت الرسالة بتطوير و تنفيذ منهج علمي جديد لحساب كمية الفواقد في شبكة مياه صنعاء وغيرها. بغرض قياس مدى وعي الموظفين بقضايا الفاقد، استخدمت الدراسة نهج المقابلات الشخصية و تحليل التقارير المتوفرة ومن ثم قامت الدارسة بتوزيع استبانة قياس الوعي مستخدمة مقياس لايكرت الخماسي. بهدف تقديم توصيات ادارية ملائمة للفاقد في المؤسسة، قامت الدراسة باستخدام التحليل الشجري للمشكلة و توزيع نوعين اخرين من الاستبانة: استبانة المجتمع واستبانة مستخدمي المياه بطريقة غير قانونية.

توصلت الدراسة الى ان كمية الفاقد في شبكة مياه مدينة صنعاءهي 38.75% ، منها 26.57% فواقد إدرية، 11.67% فواقد فيزيائية، و 0.51% استخدام قانوني غير مفوتر. علاوة على ذلك، وجدت الدراسة بان 50% من كمية الفاقد هي سرقات مياه من خلال توصيلات غير قانونية، وأوزعت السبب الى ضعف علاقة المؤسسة بمشتركيها و كذلك ضعف اجراءات الرقابة. بالرغم من ان الدراسة اوضحت ان ما يزيد عن 5% من المورد المتجدد لحوض صنعاء يذهب فاقد فيزيائي، وجدت الدراسة ان تخفيض الفاقد الفيزيائي عن تطريق تحزيم الشبكة هو خارج إطار القدرات التقنية للمؤسسة. بناء على ذلك ، اوصت الدراسة بالعمل على تخفيض الفاقد من خلال تقليل مدة اصلاح التسريبات التي يتم الابلاغ عنها ، و كذلك اشراك القطاع الخاص بادخال التكنلوجيا المناسبة لتحقيق تحزيم وإدارة شبكة المياه في مدينة صنعاء. من جهة أخرى، اوصت الدراسة بالعمل على تحسين علاقة المؤسسة بالمشترك وكسب ثقة المشتركين و ايضا التركيز على تحقيق التزام واخلاص موظفي المؤسسة من اجل تخفيض الفاقد الإداري. لتحقيق إدارة فواقد اكثر كفاءة، اقترحت الدراسة استخدام البرامج الحاسوبية المجانية لحساب الفواقد واستغلال مخرجاتها من مؤشرات أداء تضمن رقابة فاعلة لإدارة الفاقد.